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THE INSTITUTE OF PETROLEUM

AN Ordinary General Meeting of the Institute of Petroleum was held at 61 New Cavendish Street, London, W.1, on 1 October 1958, the Chair being taken by C. M. Vignoles, C.B.E., President of the Institute.

The General Secretary read the minutes of the previous meeting, which were confirmed and signed as a correct record. He also announced the names of members elected since the previous meeting.

The following paper was then presented in summary.

FUELS AND LUBRICANTS FOR THE TRANS-ANTARCTIC EXPEDITION *

By D. L. PRATT,† G. M. CHRISTIE,‡ E. F. COXON ‡ (Fellow), and J. R. LODWICK ‡ (Associate Fellow)

SUMMARY

This paper gives an account of the fuel and lubricant requirements for the equipment of the Trans-Antarctic Expedition. It describes work carried out at the BP Research Centre at Sunbury-on-Thames, and elsewhere, which led to the choice of fuels and lubricants for the tracked vehicles, aircraft, and generating equipment. The supply of materials for miscellaneous purposes, such as cooking and de-icing, is also discussed.

Emphasis is placed on the ways in which the special requirements, dictated by the vehicle types used and the arduous conditions under which they operated, were met.

Some of the studies on the behaviour of equipment and materials at low temperatures are reported. An account is given of the behaviour, under Antarctic conditions, of the fuels and lubricants.

INTRODUCTION

SOME 6,000,000 square miles of unexplored territory lie between the latitudes of 60° and 90° S.

This Antarctic Continent consists of a huge inland plateau of rolling snow country between 9000 and 11,000 feet high. Here and there mountain ranges pierce the plateau snow fields. From the inland ice sheet immense glaciers, sometimes forcing their way into the floating ice shelves, flow down to the coast. As these flow around and over obstacles in the shape of mountain ranges, on the surface and submerged beneath the ice, giant rifts and crevasses are formed, making much of the country impassable. Along the coast, ice shelves encounter the forces of tide and wind which cause the occasional breaking off of huge sections. Some of these have been observed up to 90 miles in length.

For centuries men wondered what there was at the bottom of the world. In 1820 the Englishman Bransfield first sighted the white coasts of Antarctica. Since that time many men have carried on the work of exploration, and such names as Amundsen and Scott will always remain in history. The gallant failure of Shackleton in 1914 pointed the way for Fuchs in 1955.

In these days, a journey must be both scientific and exploratory. Geology, glaciology, meteorology, physiology, and survey were the main avenues for the scientific work of the Trans-Antarctic Expedition.

To enable scientists to go into the field, travel, and carry out their studies, engineers, technologists, aviators, and field men must play their parts.

THE ROUTE TAKEN BY THE TRANS-ANTARCTIC EXPEDITION

The Plan

Dr, now Sir Vivian, Fuchs planned to sail to the Antarctic in 1955 and set up a base camp to be called Shackleton somewhere on the Filchner ice shelf. In 1956 part of the Expedition returned to London, leaving behind an advance party at Shackleton to consolidate the base. The plan was for the London party to return

* MS received 14 August 1958. † Chief Engineer, The Trans-Antarctic Expedition. ‡ The British Petroleum Co. Ltd.

to Shackleton to arrive early in 1957. This meant that the final ordering and testing of all equipment would have to be completed by November 1956.

Simultaneously with the arrival at Shackleton, the support party from New Zealand would set up a base camp, Scott Base, at McMurdo Sound. This was led by Sir Edmund Hillary and had the task of pioneering a route through the mountains and then laying depots at distances up to 700 miles inland.

Starting in October 1957, the main party was to make a transcontinental journey of exploration and scientific investigation from Shackleton Base to Scott Base, a distance of some 2250 miles. In order to carry out this plan successfully, a great deal of work was necessary to select and test special products which would meet the anticipated conditions. Thus, not only was it necessary to provide fuels, lubricating oils, and greases capable of giving adequate performance in altogether special circumstances, but much preparatory work had to be carried out in connexion with the choice, modification, and efficient operation of all the equipment concerned.

FUEL AND LUBRICANT REQUIREMENTS

Before 1955 wind speeds of up to 200 miles per hour and temperatures down to −79° F had been recorded in the Antarctic, and it was obvious with conditions such as these that considerable care was necessary in the selection of anything to be used by the Expedition. It was considered essential to use universal fuels, oils, and greases where possible to improve logistic reserve factors and simplify the work of operators.

After much consideration it was decided by the Expedition that the products required should satisfy the following general requirements:

1. They should withstand without deterioration storage temperatures down to −90° F in the Antarctic and also tropical conditions while being carried as deck cargo.
2. Those for the tracked vehicles should enable operation up to an altitude of 10,000 feet, and over the ambient temperature range +32° F to −60° F. (While it was intended that engine preheaters should be fitted and used to guarantee engine starting at an ambient temperature of −60° F, it was hoped that unassisted cold starting would be possible in an emergency at −40° F.)
3. One type only of motor gasoline was to be used, and this was required to cater for engines with compression ratios between 8·5 : 1 and 6 : 1.
4. One type only of aviation gasoline was to be used, and it was required to satisfy the fuel requirements of Auster, Otter, and Beaver aircraft.
5. One type of fuel was required to satisfy the requirements of oil lamps, primus stoves, and diesel generators. The primus stoves were to be capable of operation down to −70° F. The diesel generators would be running inside a hut, and it was expected that normal starting temperatures would be −10° F and running ambient air temperatures up to +60° F.

The time available to meet these requirements was short, and all necessary work had to be completed between 2 June 1955 and 1 November 1955, so that all the necessary materials were available for the first shipment with the advance party when they sailed in November.

EQUIPMENT

Tracked vehicles and aircraft have, of course, been used in the Antarctic before, but the requirement that equipment was to operate at temperatures as low as −60° F was particularly stringent. This requirement influenced the decision to use gasoline engines rather than diesel for all field equipment, and this choice materially reduced the magnitude of the low temperature starting problem.

Broadly, equipment can be divided into " winterized " and " non-winterized " categories. Winterized equipment may be expected to operate satisfactorily at ambient temperatures ranging from +125° F to −60° F, while non-winterized equipment will give satisfactory operation from +125° F to −25° F without the use of ancillary preheaters.

All the mechanical equipment was fitted with either a preheater system or low temperature aids to starting, and this involved a long and thorough programme of vehicle modifications, in the course of which substantial assistance was provided by each manufacturer concerned. On the engineering side of the Expedition, some 96 companies co-operated willingly in every way. Messrs Joseph Lucas and Rotax Ltd generously allowed the use of their cold chamber facilities to such an extent that cold chamber tests ran into 340 hours, while the British Petroleum Company also carried out a considerable amount of low temperature work.

The equipment used by the Expedition, for which petroleum products were required, consisted of tracked vehicles, aircraft, diesel generators, and ancillary items as follows:

Tracked vehicles:	4 Sno-Cats 4 Weasels 1 Muskeg 2 Ferguson tractors	(for the crossing party)
	5 Ferguson tractors 1 Weasel	(for the Ross Sea party)
Aircraft:	1 Otter 1 Auster	(for the crossing party)
	1 Beaver 1 Auster	(for the Ross Sea party)
Diesel generators:	2 Enfield 6-kW sets (crossing party) 5 Enfield 6-kW sets (Ross Sea party)	
Ancillary equipment:	Engine preheaters 300 W JAP engine battery chargers Hand crank petrol burning preheaters Base cooking and heating stoves Primus stoves	

TRACKED VEHICLES

Tucker Sno-Cat

Some of the more important details concerning the Sno-Cats and their modification are:

Engine	Chrysler IND 56 V-8
Power output	200 b.h.p. at 4000 rev/min
Compression ratio	8·5 : 1 (see later paragraph relating to modification)
Oil pressure	45 to 55 p.s.i. at 2000 rev/min
Crankcase capacity	5 quarts
Driving axles (front and rear)	Normal 1-ton Dodge with short extension axles fitted to carry the pontoon outer bearings
Weight (dry)	7000 lb
Steering	Front and rear steering platforms connected with swivel pins through a system of rods and levers to a hydraulic jack. The conventional steering wheel actuates the hydraulic valve to operate the jack through a steering box and levers
Track rollers	Each Sno-Cat is fitted with 296 track rollers, each of which contains caged ball bearings with a grease fitting for lubrication purposes. The unit is not waterproof
Instrumentation	Full instrumentation was fitted.
Dimensions	20 feet long × 7 feet 5 inches wide × 7 feet 6 inches high

The more important modifications made were:

(*a*) Raising the compression ratio from 7·5 to 8·5 to improve—

(i) thermal efficiency and thus fuel economy;

(ii) power output, which would be invaluable when travelling on the polar plateau at 10,000 feet.

(*b*) A mechanical system of tappet operation was substituted for the standard hydraulic operation.

(*c*) Thermostats controlling the coolant temperature at 180° F were fitted to ensure the optimum engine working temperature.

(*d*) A 24-volt electrical system was fitted in place of the standard 12-volt equipment.

(*e*) A normal clutch and five-speed gear box was substituted for the Chrysler fluid torque drive.

(*f*) A hand-operated means of fuel injection was fitted to the engine manifold.

(*g*) A fuel filter sediment bowl, electric pumps, and micro filters were incorporated in the fuel system.

(*h*) A kerosine burning preheater in the engine coolant system was installed following an extensive development programme. This preheater was also arranged so that the starting batteries, which were of the low temperature multi-plate type, could be heated when necessary.

Weasel

The Weasel is a cargo carrier which was manufactured in the U.S.A. between 1939 and 1945 as an army vehicle (all available Weasels were thus necessarily second-hand).

General Details

Engine	Studebaker straight 6
Power output net (at sea level)	75 b.h.p. at 3800 rev/min
Power output net (at 3000 feet altitude)	55 b.h.p. at 3600 rev/min
Compression ratio	7 : 1
Oil pressure	40 p.s.i.
Crankcase capacity	5 quarts
Weight (dry)	4800 lb
Dimensions	14 feet 6 inches long × 5 feet 7 inches wide × 7 feet 3 inches high

The Weasels obtainable were in poor condition and had to have a complete overhaul, during which an extensive programme of mechanical strengthening was carried out. This included the use of heavier springs, driving sprockets, and the fitting of heavy duty gear boxes, etc. An electrically-operated, kerosine-burning type of preheater was fitted to blow hot air on to the engine and batteries, which were of the special multi-plate low temperature type. A hand priming fuel injector system and a full range of instruments were installed.

Muskeg

The Muskeg tractor is a Canadian-built vehicle, general details of which are as follows:

Engine	Chrysler straight 6 (side valve)
Power output	115 b.h.p. at 3400 rev/min
Compression ratio	7 : 1
Crankcase capacity	5 quarts
Weight (dry)	4600 lb
Dimensions	11 feet 8 inches long × 7 feet 3 inches wide × 5 feet 8 inches high

In the time available it was only possible to modify these tractors to incorporate a low temperature battery and drift-proofing of the cab and engine compartment. This work was actually carried out in the Antarctic.

Ferguson

The Ferguson tractor is British built and Model TE20 was used, with full tracks over the front and rear wheels. The complete tractor is manufactured for Massey-Ferguson Ltd by the Standard Motor Company.

General Details

Engine	Standard O.H.V. governed mechanically to 2000 rev/min maximum
Power output	28·2 b.h.p. at 2000 rev/min governed
Compression ratio	6 : 1
Crankcase capacity	6 quarts
Weight (dry)	3370 lb
Dimensions	10 feet long × 6 feet 1 inch wide × 4 feet 4 inches high

Modifications. Some of the modifications were as follows:

1. Fitting of a special reduction gear box.
2. Fitting of low temperature batteries, and low temperature electrical leads.
3. Fitting of a more powerful starter motor.
4. An updraught carburettor was fitted in place of the more usual downdraught type.
5. A hand-operated fuel injector primer was provided.

AIRCRAFT

Auster

These were extensively modified and re-equipped for the purpose of reconnaissance and support in the Antarctic.

General Details

Engine	Gipsy Major 7G Type air-cooled inverted 4 cylinder in line
Power output	145 b.h.p. unsupercharged
Propeller	2-blade Fairey Reed type, fixed pitch

They were to be used with floats from the ship for ice reconnaissance, and converted to skis in the Antarctic for use in the field. The modifications were based on experiences in the 1949–50 Norwegian–British–Swedish Antarctic Expedition.

Modifications

1. Normal oil dilution system was fitted to the engine to facilitate starting. This is the standard system of admitting a measured amount of petrol to the engine oil before switching off the engine.
2. A fuel primer pump was fitted.
3. A Coffman starter unit was fitted for starting the engines.
4. The electrical system was changed from 12 to 24 volts.

Otter

The crossing party was to use this aircraft for reconnaissance and support. The Otter was also scheduled for the Trans-Antarctic flight. This aircraft was built by The de Havilland Company of Canada Ltd. It can operate from land, water, and snow surfaces. In the present Expedition it was fitted with skis and was to take off and land on snow.

General Details

Engine	Pratt and Whitney Wasp R1340
Type	9-cylinder air-cooled radial
Power	600 b.h.p. supercharged
Propeller	Hamilton standard, 3-blade, constant speed, counter weight type

The plane is fitted with (as standard) a fuel priming hand pump and oil dilution.

Modifications. Installation of a heavy duty, low temperature battery.

Beaver

The Beaver is an all-metal, high wing monoplane built by The de Havilland Company of Canada and was used by the Ross Sea party for reconnaissance, support, and depot laying.

General Details

Engine	Pratt and Whitney Wasp junior
Type	9-cylinder air-cooled radial
Power	450 b.h.p. (supercharged)
Propeller	Hamilton standard, 2-blade, constant speed, counter weight propeller

The plane is fitted with (as standard) a fuel priming hand pump and oil dilution.

Modifications

1. Installation of a special low temperature battery.
2. The fitting of a winter engine nose shutter.

ANCILLARY EQUIPMENT

Auto Diesels 6-kW Generating Sets

These sets were to be used indoors at the base camps.

General Details

Engine	Horizontally-opposed twin-cylinder with a swirl combustion chamber made by Enfield Industrial Engines Ltd.
Alternator	6kW, single phase.
Power output	13·25 b.h.p.

Engine Preheaters

An electrically-operated Smith's kerosine-burning heat exchanger was used for coolant heating on the Sno-Cats. In this appliance fuel drawn from the supply tank by an electrically-operated piston pump is delivered through a swan-necked pipe into an atomizing cup which, rotating at a speed of 3500 rev/min, discharges it as a spray to mix with the incoming combustion air. Combustion is initiated by means of a glow plug, but during operation this is inoperative. This 50,000-B.t.u/hr unit was designed to operate on kerosine, but it was required to know if it would run on gasoline or a gasoline/kerosine blend in the possible absence of kerosine in the field.

The type 50 ASM Smith's air heaters were used on the Weasels. This heater works on a similar principle to the coolant heater except that it heats air instead of coolant.

SUPPLY OF FUELS, LUBRICANTS, AND SPECIAL PRODUCTS

In the short time available from 2 June to 1 November 1955 it was necessary to select and test the fuels, lubricants, and special products and to package these

materials suitably. It was also felt desirable to check the behaviour of some of the materials chosen in some of the equipment to be taken to the Antarctic. At the same time a literature survey was carried out to provide as much data as possible concerning the behaviour of fuels, lubricants, and engines under low temperature conditions, but little published data were available which discussed temperatures below −65° F down to the requisite Antarctic extreme temperatures of −80° to −90° F. A bibliography of the more important literature references is given at the end of the paper.

After a preliminary study of all the factors involved, it was considered that both fuels and lubricants could readily be prepared from petroleum-based materials for use in all types of equipment to cover the Antarctic summer temperature range from +30° to about −40° F. It was also apparent that products were already available which were suitable for use in winterized equipment over the ambient temperature range of +60° to −65° F.

In making the choice of fuels and lubricants the requirements of the Expedition as outlined on p. 20 were of paramount importance and were met as closely as possible.

The methods of test used to determine the data given in the tables below were those specified in the relevant specifications.

SUPPLIES FOR TRACKED VEHICLES

Tucker Sno-Cats

Fuel. On the basis of discussions with the Tucker Sno-Cat Corporation and others it was decided that a sub-zero motor gasoline conforming to DEF-2401A should be supplied. A fuel of increased O.N. of 96 Research was provided to satisfy the requirements of the 8·5 : 1 compression ratio engines, and because of the emphasis placed on the ability to obtain starting at low temperatures the fuel was made as volatile as possible consistent with specification requirements. The general properties of the fuel supplied are given in Table I.

TABLE I

Inspection Data for Sub-Zero Motor Gasoline

Specific gravity 60°/60° F	0·6880
Distillation:	
IBP, °C	29
2% Recovered at, °C	33
5% Recovered at, °C	36
10% Recovered at, °C	40
20% Recovered at, °C	46
30% Recovered at, °C	52·5
40% Recovered at, °C	59
50% Recovered at, °C	66·5
60% Recovered at, °C	77
70% Recovered at, °C	88
80% Recovered at, °C	103
90% Recovered at, °C	123·5
FBP, °C	155
Recovery, % vol	96·5
Residue, % vol	1·5
Loss, % vol	2·0
10% Evaporated temperature, °C	38
50% Evaporated temperature, °C	65
90% Evaporated temperature, °C	118·5
Reid vapour pressure, lb	14·0
Vapour/liquid ratio 36 : 1 at, °C	45
Total sulphur, % wt	0·065
Corrosion test (copper strip at 50° C)	No change
Bromine No.	91·5
Gum existent IP 38, mg/100 ml	1
Induction period, ASTM min	>720
Induction period, IP min	530
Cold test, °C (F)	<−80 (<−112)
Aromatics, % vol	4
TEL content, ml/IG	1·35
Octane No. Motor Method	83
Octane No. Research Method	97

Crankcase Oil. The engine manufacturer recommends the use of an SAE 5W oil at temperatures below −10° F. Other sources indicated that a MIL-O-10295 oil (SAE 5W oil) was satisfactory for operating temperatures from −65° to +10° F. Field tests carried out had indicated that the oil was also satisfactory under high temperature conditions (15). In view of these facts, the use of MIL-O-10295 HD oil (SAE 5W) was recommended for the Sno-Cats.

To confirm that this oil, intended for sub-zero operation, was suitable for Antarctic summer temperatures of the order of +20° F, a Chevrolet L4 test was run for 100 hours at an oil temperature of 120° C, even though this qualified lubricant had passed the 36-hour L4 test at this temperature. Engine operation was entirely satisfactory, showing neither excessive engine deposits nor corrosion of copper/lead or white metal bearings. Data on this oil are given in the following table.

TABLE II

Inspection Data for Crankcase Lubricating Oil

Specific gravity at 60°/60° F	0·8905
Flash point COC, °F	310
Flash point, PM closed, °F	275
Kinematic viscosity at −40° F, cS	6655
Kinematic viscosity at 100° F, cS	25·1
Kinematic viscosity at 140° F, cS	13·5
Kinematic viscosity at 210° F, cS	6·28
Viscosity index	176
Pour point, °F	<−65
Stable pour point, °F	<−65
Foaming Test:	
Sequence 1 stability 10 min	Nil
Sequence 2 stability 10 min	Nil
Sequence 3 stability 10 min	Nil
Caterpillar engine test L1 (MIL-L-2104A fuel)	Met specification requirements
Chevrolet engine test L4	Met specification requirements
Ash (sulphated), % wt	0·63
Sulphur, % wt	0·32
Phosphorus, % wt	0·064
Calcium	Nil
Barium, % wt	0·25
Zinc, % wt	0·062

Gear Oil. The lubricant recommended by the manufacturer for temperatures below −10° F was

an SAE 80 grade, but in discussion with various interested parties it was found that an oil to specification MIL-L-10324 (Ord) had been successful in sub-zero temperature operation, and consequently this grade was supplied to the Expedition. Details of the oil supplied are given later in the text.

Steering. The Sno-Cat is fitted with an hydraulically-operated power steering system. After taking into account the ambient temperatures which would be encountered, it was decided that a refined mineral oil type hydraulic fluid conforming to the DTD 585 specification should be supplied. Inspection data on this material, which was also used by the Expedition aircraft, are given in Table III.

TABLE III

Inspection Data on Hydraulic Fluid

Freedom from impurities	Free
Viscosity kinematic at 130° F, cS	10·20
Viscosity kinematic at −40° F, cS	463·6
Pour point, ° F	−100
Flash point (open), ° F	195
Neutralization value, mg KOH/g	0·07
Precipitation No.	Nil
Corrosion 168 hr at 250° F	Satisfied requirements of DTD 585
Change in wt of steel, mg/cm²	
Change in wt of aluminium alloy, mg/cm²	
Change in wt of cadmium plated steel mg/cm²	
Change in wt of copper, mg/cm²	
Copper strip corrosion 3 hr at 212° F	Unchanged
Resistance to oxidation 168 hr at 250° F	Satisfied requirements of DTD 585
Change in viscosity, cS at 130° F, %	
Increase in neutralization value, mg KOH/g	0·10
Stability on storage for 72 hr at −65° F	Less cloudy than standard
Swelling of synthetic rubber	Satisfactory
Evaporation 4 hr at 150° F and cooled to room temperature	Tackiness similar to standard

Water Pump Lubricant. It was felt that although the grease supplied for the track rollers would lubricate the water pump satisfactorily at the stated engine temperature of 180° F, it might not function as a seal at that temperature. A conventional water pump grease was first supplied, but it was demonstrated in field trials in Norway that the MIL-G-10924 grease as used for track rollers was also satisfactory for water pump lubrication, and this grease was therefore used in Antarctica. Limited inspection data on this material, which was also used in the Expedition aircraft, are given in Table IV.

Track Rollers, etc., Lubricant. It was decided to use a multi-purpose grease (MIL-G-10924) suitable for low temperature use. Great care was taken to ensure that the rollers and other grease-packed bearings were filled with the correct type of grease before shipment, since it would be almost impossible to remove one type of grease and replace it with another. Arrangements were therefore made for the manufacturers to use the correct type of lubricants for the first fill. Inspection data are given in Table IV. An account of additional work carried out in proving the suitability of the grease is given in the next section.

TABLE IV

Inspection Data for Low Temperature Grease

Freedom from impurities:	
No. of particles, 25 microns or above, per cc	1030
No. of particles, 75 microns or above, per cc	Nil
No. of particles, 125 microns or above, per cc	Nil
Penetration at 77° F:	
Unworked, mm/10	260
Worked (60 strokes), mm/10	264
Drop point, ° C	140
Oil separation after 30 hr at 100° C, % wt	1·2
Oil separation after 50 hr at 160° F (71·1° C), % wt	0·7
Evaporation loss after 22 hr at 121° C (250° F), % wt	14
Evaporation loss after 22 hr at 210° F, % wt	6·3
Working stability:	
Penetration mm/10 after 100,000 double strokes in worker	295
Penetration mm/10 after 100 hr at 10 rev/min and 150° F in Shell Roller Tester	295
Bomb oxidation test at 210° F and 110 p.s.i. O_2:	
Fall in pressure after 100 hr, p.s.i.	1·5
Fall in pressure after 500 hr, p.s.i.	6
Bomb copper corrosion test 20 hr 110 p.s.i. O_2:	
Colour of grease	Slight change in colour
Colour of copper strip	
Fall in pressure after 20 hr, p.s.i.	<1
Water resistance:	
9 : 1 grease–water mixture worked 100,000 double strokes. Penetration, mm/10	310
Salt spray resistance—spray grease coated test panels for 100 hr with synthetic sea water	No evidence of corrosion
Storage in field at temperatures −65° to +125° F	Shows no appreciable physical or structural change

Consumption of Fuels and Lubricants. The question of the consumption by the Sno-Cats was of particular importance. One stage of the planned Trans-Antarctic journey involved a distance of approximately 1090 miles, on which all supplies would have to be carried without the opportunity of replenishment. Every gallon of fuel (the largest item in the load carried) remaining at the end of the stage represented excess weight which would adversely affect fuel consumption. The ideal would be to arrive at the end of the stage at the replenishing point with empty vehicle tanks. It was therefore essential to carry out a field trial in snowy conditions, and three Sno-Cats were transported to the Jotunheinen district of Norway, where trials were carried out at altitudes between 4150 and 4500 feet and daily ambient temperatures of 37° to 48° F, falling at night to freezing point. These trials were carried out to evaluate fuel

and lubricant consumption, and to assess the general performance of the vehicles and of the products to be used.

Under the conditions encountered during the trials it was found that the fuels, engine oil, and transmission lubricants were satisfactory in all respects. It was established that the gasoline consumption was 1·41 m.p.g. laden and 1·65 m.p.g. unladen, crankcase oil and gear plus transfer box oil consumptions were 4 gallons and about 1 pint per 500 miles respectively. The axle oil consumption was not excessive, and it was established that track roller lubrication could be carried out satisfactorily by filling the bearings completely and allowing the excess grease to work out. The operation of the Sno-Cat steering mechanism, water pump bearings, and general engine behaviour was satisfactory.

As the ambient temperatures experienced in Norway, *i.e.* 30° to 40° F, were not as low as was desirable and because difficulties had been reported with the track rollers, it was decided to carry out a series of rig tests on the track roller bearings. A rig was designed for low temperature tests in which the bearings were tested with a radial load of 200 lb when running at an equivalent road speed of 8 m.p.h. and with ambient temperatures varying between +15° and −50° F. The rig was used to simulate operation for 2000, 2500, and 3000 miles and the grease (MIL-G-10924) provided adequate lubrication, but localized pitting of the bearing tracks occurred. This was considered to be due to severe work hardening and metal fatigue of the track material. Although there was evidence of some damage to the bearings, for practical purposes the bearings were serviceable for many more miles of operation. It was not, therefore, considered that undue difficulties would be encountered by the Expedition over the mileages expected to be covered if the test conditions were similar to those to be met in the field.

While, in the foregoing paragraphs, emphasis has been given to products for the Sno-Cat, a great deal of useful information which could be applied to other vehicles was gained.

Ferguson Tractors

The following account summarizes the more important aspects of the work carried out by the British Petroleum Co. Ltd, and all discussions held with the representatives of the tractor manufacturers aimed at finalizing the choice of fuels and lubricants.

Fuel. A DEF-2401A sub-zero grade motor gasoline having a Reid vapour pressure of 12–14 lb was considered suitable, but the manufacturers were a little concerned regarding the maximum permissible lead content of 3·6 ml TEL/IG. However, assurances were given that the TEL content of the gasoline to be supplied would not exceed 1·5 ml/IG and, in fact, the same motor gasoline was supplied as for the Sno-Cat vehicles, this having a TEL content of 1·35 ml TEL/IG (see Table I).

Crankcase Oil. Discussions with representatives of Massey-Ferguson Ltd confirmed that a MIL-O-10295 HD SAE 5W oil as was proposed for the other tracked vehicles in the Expedition would be suitable for the Ferguson tractors. The manufacturers, in common with other authorities, did not favour the possible alternative of diluting a high viscosity oil for starting purposes (see Table II).

Gear Oil. It was originally suggested that a gear oil equivalent in viscosity to an SAE 20W crankcase oil, but suitably fortified, possibly to SAE 90 film strength, would be satisfactory. On discussing this point in the light of experiences quoted in the literature on the subject of low temperature operation, it became apparent that the operating temperatures involved demanded the use of an SAE 75 gear oil, equivalent in viscosity to an SAE 10W crankcase oil. This oil would, however, be a full EP grade. Information then became available that an even lighter grade to specification MIL-L-10324 (Ord) had been used satisfactorily. It was pointed out by the manufacturers that a common oil was used in the whole of the transmission (gear box and rear axle) and the hydraulic system, that the hydraulic system contained phosphor-bronze components, and that the EP oil was therefore not acceptable. In addition, a straight oil was normally recommended for the above use to avoid the risk of unusual behaviour of the rubber seals in the hydraulic system. In order to clear this aspect of lubricating oil supply, a number of samples of tractor hose and pump rings were sent to the BP Research Centre for immersion tests in gear oils.

A low viscosity, low pour point oil was investigated and looked promising. Since the tractors might have been used at temperatures of 30° to 40° F at periods, it was necessary to improve the load-carrying capacity of the oil by the addition of a load-carrying additive which would not be detrimental to the phosphor-bronze components. After deciding on the lubricant it was necessary to find suitable hose and pump rings which would not give excessive swelling in the lubricant suggested. A variety of materials was examined, and eventually hose and pump rings were selected which gave quite low swelling after immersion in the lubricant. These materials, hose, pump rings, and oil, were the ones finally selected for use in the tractors.

Details of inspection data and load-carrying capacity tests on the additive-type oil are shown in Table V, and are compared with the gear lubricant used in the other tracked vehicles. The load-carrying capacity was superior to that of a neat SAE 50 grade, as recommended by the manufacturers, in the IAE gear machine.

Bearing Hub and Steering Box Lubricant. The

above mentioned additive-treated oil was regarded as suitable for all applications where the transmission oil was recommended and was accordingly considered suitable as a front wheel bearing hub and steering box lubricant.

Grease. There were no critical requirements for greases nor for grease gun application to bearing nipples or water pump other than adequate performance at low temperatures. A multi-purpose low-temperature grease, such as MIL-G-10924 (Table IV), was regarded as satisfactory. The point was stressed with the manufacturers that any nipples or bearings should be initially packed at the works with grades of greases or oil meeting specifications equivalent to those stipulated for the Expedition. Having selected the fuels and lubricants, it was necessary to prove their performance as far as was possible under low temperature conditions.

TABLE V

Inspection Data for Gear Oil Supplied

Test	Gear lubricant for Ferguson tractors	MIL-L-10324 (Ord) gear lubricant as supplied for Sno-cats and Weasels
Specific gravity at 60°/60° F	0·891	0·922
Flash point COC, ° F	330	300
Kinematic viscosity at −65° F, cS	—	50,000 *
Kinematic viscosity at −40° F, cS	5825	5,325 †
Kinematic viscosity at 0° F, cS	427·5	352
Kinematic viscosity at 100° F, cS	13·6	12·9
Kinematic viscosity at 140° F, cS	6·79	6·63
Kinematic viscosity at 210° F, cS	2·96	3·01
Viscosity index	67	96
Pour point, ° F	< −65	< −65
Ash sulphated, % wt	0·25	0·03
Copper corrosion 1 hr at 250° F	No change	No blackening
Phosphorus, % wt	0·080	0·042
Chlorine, % wt	—	2·39
Zinc, % wt	0·083	—
Saponification value, mg KOH/g	—	22·0
Mean scuffing load in 3½-inch IAE gear test, lb	147·5 ‡	—

* By extrapolation using 0° F and 210° F viscosities.
† Estimated.
‡ Straight SAE 50 grade as recommended by the manufacturers gave a result of 66 lb.

Work Carried Out Under Conditions of Extreme Cold. The opportunity arose for carrying out starting tests on the Ferguson tractors at low temperatures and these were carried out, thanks to the co-operation of Messrs Massey-Ferguson Ltd, Joseph Lucas, and Rotax Ltd, in the cold chamber in the works of the last-named at Hemel Hempstead. The objects were to assess the performance of the fuels and lubricants and the modified electrical equipment and batteries. The full range of modifications proposed for use in Antarctica was incorporated. The tractor remained in the cold chamber overnight at a temperature of —40° F, and during the next morning an initial cranking was carried out, mainly to bring the special low temperature batteries to a condition of approximately 70 per cent charged, ready for the main test in the afternoon. Immediately before the main test was started (the cold chamber air temperature thermometer reading —40° F), the oil dipstick was removed from the oil sump and the oil temperature measured. This, together with the coolant temperature, was —38° F. The carburettor choke was operated in the normal way, starting switch closed, and the fuel priming system pump operated. The starting signal was given to co-ordinate these operations. Timing with a stop-watch showed that the engine fired momentarily after cranking for 5 seconds and fired regularly after a further 8 seconds. It then continued to run for an additional minute until it was stopped. This was considered a satisfactory performance under these conditions. From these tests it was considered that fuels and lubricants had been correctly chosen and that the sub-zero grade of fuel would be suitable for other tracked vehicles.

Studebaker Weasel

A sub-zero grade of fuel was provided as for the other tracked vehicles, and methanol was also supplied so that it could be added to the fuel in the event of icing troubles being encountered. The consideration of information available indicated that MIL-O-10295 HD SAE 5W oil (Table II) was the correct lubricating oil to use in the crankcase and MIL-L-10324 (Ord) (Table V) oil was the correct oil for the transmission under conditions of low temperature operation.

A MIL-G-10924 (Ord) grease (Table IV) was supplied for the lubrication of universal joints and track bearings, wheels and sprockets, and general purposes.

The fuels and lubricants selected for the tracked vehicles are shown in summarized form in the following table.

TABLE VI

Schedule of Fuels and Lubricants for Tracked Vehicles

Product	Specification U.K. and/or U.S.A. and/or Canadian	Remarks
Motor gasoline	U.K. DEF-2401A (80 O.N. sub-zero) U.S. MIL-G-3056A Type II	Supplies 1·35 ml TEL/IG, 96·6 O.N. (RM)
Lubricating oil crankcase	U.S. MIL-O-10295 (Ord)	Supplies to SAE 5W MIL-O-10295
Lubricating oil gear	U.S. MIL-L-10324 (Ord)	For Sno-Cats and Weasels only
Lubricating oil gear	Special formulation	For Ferguson Tractors only
Hydraulic oil	U.K. DTD 585 U.S. MIL-O-5606 (AM 2)	Supplies to DTD 585
Lubricating grease (low temp)	U.K. DTD 825A U.S. MIL-G-10924 (Ord) U.S. MIL-G-3278	As for aircraft to MIL-G-10924 (Ord)
Cylinder inhibitor	U.K. DTD 791B	Supplies to DTD 791B
Methanol	U.K. B.S. 506 : 1950	Supplies to B.S. 506:1950

SUPPLIES FOR AIRCRAFT

The choice of fuels and lubricants for the Auster, Otter, and Beaver aircraft was made in such a way as to satisfy the recommendations made by the manufacturers, to which, in the main, the materials supplied conformed.

Fuel

In selecting the fuel, discussions with engine and aircraft manufacturers indicated that for the DH Gipsy Major 7G engine of the Auster aircraft, fuel meeting the requirements and specification of D ENG 2485, 80 octane minimum, but with up to 4 ml TEL/IG would be suitable. Such a fuel would also meet the needs of the Pratt and Whitney engines on the Otter and Beaver aircraft, except that a lower lead content gasoline was specified for these aircraft (*i.e.* Canadian 80/87 grade 3-GP-25c) and the fuel supplied contained 0·73 ml TEL/IG.

Lubricating Oil

Engine lubricating oil meeting the requirements of specification D ENG RD 2472 A/O was selected, and had in fact previously been used in the Antarctic in Auster aircraft by the 1949–50 Norwegian–British–Swedish Antarctic Expedition. This oil was also considered suitable for the Beaver and Otter aircraft.

Standard oil dilution equipment was fitted to all engines and for the DH Gipsy Major of the Auster aircraft its use was considered necessary if the expected starting temperature was below −5° C. The recommended order of dilution was approximately 25 per cent volume fuel and the minimum starting temperature under these conditions was considered to be −40° C.

Other Products

In addition to the lubricating oil so far mentioned, other products were used by the Norwegian–British–Swedish Expedition of 1949–50. These were: anti-freeze oil, low temperature grease DTD 825, graphited wax BSM 825, grease for wheel hubs (not required as the aircraft were fitted with skis or floats), protective materials, lanolin solution, and corrosion inhibitor.

Following discussions with the manufacturers, these or closely similar products were adopted. In addition, the following materials were required for inhibiting purposes for the Auster aircraft: storage oil to specification DTD 698, cylinder protective wax thickened to DTD 791, lanolin resin protective to specification DTD 663A, anti-freeze oil to specification DEF 2001, small quantities of anti-freeze grease to specification DTD 825A, and pure white lanolin to specification DTD 122C. These materials were also considered suitable for inhibiting the Beaver and Otter aircraft.

Detailed inspection data on the aviation fuel, the crankcase lubricating oil, anti-freeze oil, the low temperature grease which was used both for the Expedition aircraft and tracked vehicles, cylinder inhibitors, and anti-seize grease are given in Tables VII, VIII, IX, IV, X, and XI respectively.

TABLE VII
Inspection Data for Aviation Fuel

Specific gravity at 60° F/60° F	0·7235
TEL content, ml/IG	0·73
Cu strip corrosion (3 hr at 100° C)	Passes
Distillation:	
Evaporated at 75° C (167° F), % vol	28
Evaporated at 105° C (221° F), % vol	67
Evaporated at 135° C (275° F), % vol	95
Sum of 10% and 50% evaporated temperatures, ° C	155
Final boiling point, ° C	159
Residue, % vol	1
Loss, % vol	1
Freezing point, ° C	Below −60
Gum existent, mg/100 ml	<1
Gum accelerated, mg/100 ml	1
Gum precipitate, mg/100 ml	Nil
Total sulphur, % wt	0·004
Reid vapour pressure at 100° F, lb	6·2
Water reaction test	Nil
Aniline-gravity product	7564
Lean mixture knock rating Octane No. motor method	84
Rich mixture knock rating Octane No.	90

TABLE VIII
Inspection Data for Crankcase Lubricating Oil for Aircraft

Specific gravity	0·882
Kinematic viscosity at 100° F, cS	178·1
Kinematic viscosity at 140° F, cS	60·0
Kinematic viscosity at 210° F, cS	16·18
Viscosity index	102
Flash point COC, ° F	505
Pour point, ° F	−15
Pour point diluted, ° F	<−70
Cloud point, ° F	10
Neutralization value, mg KOH/g	<0·05
Reaction	Neutral
Mineral acidity	Nil
Carbon residue (Ramsbottom), % wt	0·18
Copper corrosion test	No change
Sulphur content, % wt	0·14
Ash content, mg/20 g	0·6
Precipitation No., % vol	Slight trace
Saponification value, mg KOH/g	0·25
Proof of satisfactory performance in aircraft or type engine test	Approved Formulation D ENG RD 2472A/O

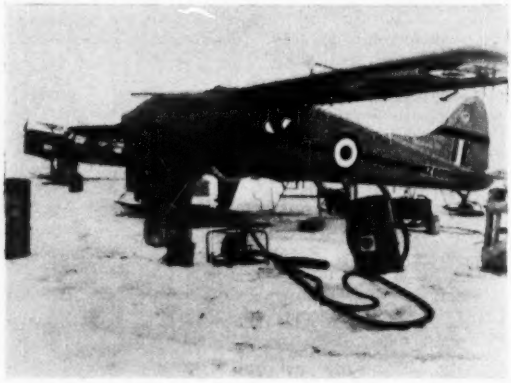
TABLE IX
Inspection Data for Anti-freeze Oil

Colour ASTM	3
Kinematic viscosity at 100° F (37·8° C), cS	11·14
Kinematic viscosity at −15° F (−26° C), cS	625·2
Kinematic viscosity at −40° F (−40° C), cS	3,597
Flash point (closed), ° F	285
Aniline point, ° C	74·8
Pour point, ° F	−80
Inorganic acidity, mg KOH/g	Nil
Organic acidity	Nil
Saponification value, mg KOH/g	0·33
Precipitation No.	Nil
Copper strip corrosion (3 hr at 100° C)	Unchanged
Low temperature stability. Storage at −54° C (−65° F) for 72 hr	Satisfactory

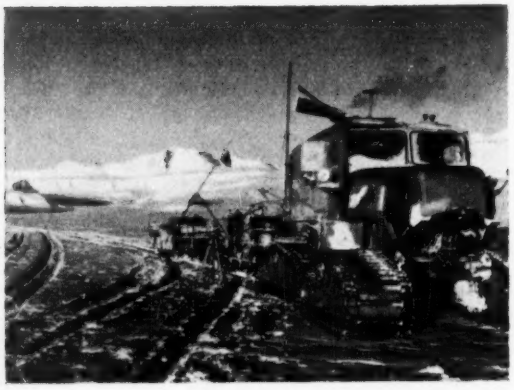
TRANSPORT IN ANTARCTICA

Some pictures taken during the Trans-Antarctic Expedition

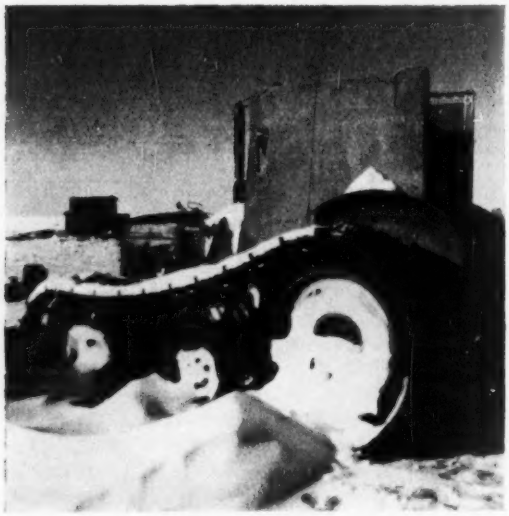
WEASEL VEHICLE AT THE SOUTH POLE



PRE-HEATING THE ENGINE OF THE BEAVER AIRCRAFT AT SCOTT BASE



SNO-CAT HAULING TWO SLEDGES ON SKELTON GLACIER

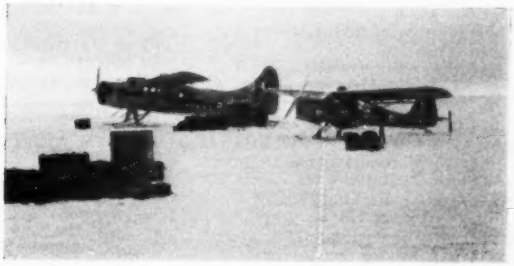


NEW ZEALAND PARTY'S FERGUSON TRACTOR AT SOUTH POLE AFTER JOURNEY FROM SCOTT BASE

MUSKEG IN FOREGROUND OF VEHICLE CONVOY CAMPED IN FIELD OF SASTRUGI

WEASEL IN CREVASSE ON JOURNEY TO SOUTH ICE

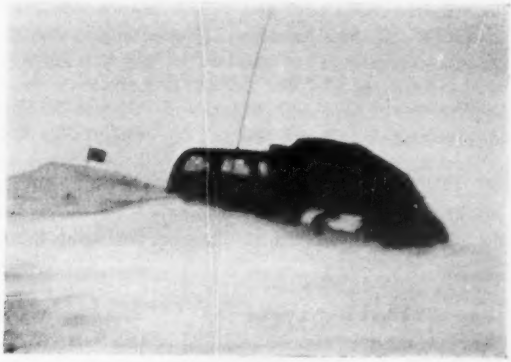
SNO-CAT IN CREVASSE ON JOURNEY TO SOUTH ICE



THE OTTER AND AUSTER ON SKIS PICKETTED DOWN AT SHACKLETON BASE

MUSKEG TRACTOR WITH CREVASSE BRIDGES TIED UPON RUNNING BOARDS

GREASING SNO-CAT TRACKS



ENGINE REPAIR IN BLIZZARD

TABLE X

Inspection Data for Cylinder Inhibitors

Freedom from impurities	Free from dirt
Dirt and visible impurities	Some solid wax present which was dispersed by shaking
Lumps or aggregates not dispersed on shaking	
Water, % vol	Absent
Stability of wax dispersion: % Volume of separation of clear liquid after standing 24 hr being well shaken and standing for an additional 6 hr at 20° ± 5° C	1
Distillation range:	
IBP, ° C	50
FBP, ° C	165·5
Recovery at 100° C, % vol	42·5
Recovery at 160° C, % vol	78
Total recovery, % vol	79
Wax content determined, % wt	6·6
Freedom from corrosive substances at 100° C for 24 hr:	
Steel panels	No corrosion
Aluminium panels	No corrosion
Copper panels	Slight uniform stain

TABLE XI

Inspection Data on Anti-seize Grease

Composition	To DTD 392
Mineral jelly, % wt	50
Graphite, % wt	50
Consistency worked at 25° C, mm/10	181
Ash, % wt	0·5
pH of aqueous extract	7·1
Stability on centrifuging at room temperature for 30 min at 1500 rev/min	No separation

A summary of the products supplied for the aircraft is given in table form below:

TABLE XII

Schedule of Fuels and Lubricants for Aircraft

Product	Specification U.K. and/or U.S.A. and/or Canadian	Remarks
Aviation gasoline	U.K. 80 Grade DERD 2485 Canadian 80/87 Grade 3-GP-25c	
Lubricating oil	U.K. DERD 2472A/O U.S. MIL-O-6082 (1080) Canadian 3-GP-80A	Supplies to D ENG RD 2472 A/O
Anti-freeze oil	U.K. DEF-2001 U.S. MIL-L-7870A	Supplies to MIL-L-7870A
Low temperature grease	U.K. DTD 825A U.S. MIL-G-10924 (Ord) U.S. MIL-G-3278	Supplies to MIL-G-10924 (Ord)
Protective coating	U.K. DTD 279B U.S. MIL-C-16173A (Grade 1)	Supplies to DTD 279B
Cylinder inhibitor	U.K. DTD 791B	Supplies to DTD 791B
Lanolin resin	U.K. DTD 663A U.S. MIL-C-11796A (Am 1)	Supplies to DTD 663A
Pure white lanolin	U.K. DTD 122C	Supplies to DTD 122C
Anti-seize grease	U.K. DTD 392 U.S. MIL-T-5544A (ASC)	Supplies to DTD 392
Petroleum jelly		
Hydraulic fluid	U.K. DTD 585 U.S. MIL-O-5606 (Am 2)	Supplies to DTD 585
Utility grease (propellers)	U.K. DTD 783 U.S. MIL-L-7711 (Am 1)	Supplies to MIL-L-7711 (Am 1)
Graphited wax	Proprietary materials	

SUPPLIES FOR STATIONARY EQUIPMENT

Auto Diesel Generating Sets

For these sets, which were to be used by the Expedition at base camps, the range of temperatures between which the engine was expected to operate was −10° to +60° F.

Lubricating Oil. The normally recommended oil for temperatures between 0° and 30° F was an SAE 10W HD lubricating oil and it was agreed that an SAE 10W HD oil of DEF 2101A quality would be satisfactory. Inspection data on the oil supplied are as follows:

TABLE XIII

Inspection Data on SAE 10W DEF-2101A *Crankcase Lubricating Oil for Generating Sets*

Specific gravity at 60°/60° F	0·892
Flash point COC, ° F	420
Kinematic viscosity at 0° F (extrapolated)	1900
Kinematic viscosity at 100° F	36·7
Kinematic viscosity at 140° F	15·8
Kinematic viscosity at 210° F	5·77
Viscosity index	108
Pour point, ° F	−25
Stable pour point MIL-L-2104A, ° F	−25
Foaming test:	
At 75° F, tendency ml	455
At 75° F, stability ml	Nil
At 200° F, tendency ml	55
At 200° F, stability ml	Nil
At 75° F after test at 200° F—	
At 75° F, tendency ml	505
At 75° F, stability ml	Nil
Neutralization No., mg KOH/g	0·15
Ash sulphated at 775° C, % wt	0·54
Copper strip corrosion	No change
Calcium, % wt	0·038
Barium, % wt	0·25
Phosphorus, % wt	0·028
Chevrolet L4 engine test *Caterpillar L1 engine test*	Qualified–oil meets the requirements of DEF-2101A

Fuel. It was proposed to supply kerosine as the fuel for the Auto diesel electric generating sets. This proposal was discussed with the Enfield representatives, who said that they had successfully tested an engine on kerosine although, as a precautionary measure, 5 per cent of lubricating oil had been added to the fuel. Because rough engine running and diesel knock had been reported by previous expeditions when a light, low pour point gas oil had been used, it was decided that bench tests should be carried out on the kerosine proposed for the Expedition. This work gave no indication of unusual behaviour, the only comments made being that the injector leak-off was higher than on normal diesel fuel and that the volumetric specific fuel consumption was about 5 per cent higher; on a weight basis the specific fuel consumption with kerosine was little inferior to that with gas oil. Samples of the lubricating oil examined during the test for fuel dilution were entirely satisfactory. The

injector leak-off in this engine is normally taken to the inlet port, but in view of the high rate likely to be met using kerosine, it was arranged for this to be taken back to the fuel filter. With this modification made and in view of the satisfactory test results, kerosine was adopted as the diesel fuel for the Expedition. Inspection data on the fuel supplied are given in Table XIV.

TABLE XIV

Inspection Data for Kerosine

Appearance	Clear
Colour ASTM	+30 Saybolt
Specific gravity 60°/60° F	0·7880
Distillation:	
IBP, °C	162·5
2% recovered at, °C	172·5
5% recovered at, °C	175
10% recovered at, °C	180
20% recovered at, °C	185
30% recovered at, °C	192
40% recovered at, °C	197·5
50% recovered at, °C	203
60% recovered at, °C	210
70% recovered at, °C	215·5
80% recovered at, °C	224
90% recovered at, °C	235
FBP, °C	253
Recovered at 185° C, % vol	20·0
Recovered at 200° C, % vol	43·0
Recovered at 210° C, % vol	60·0
Recovered at 240° C, % vol	93·5
Recovery, % vol	99·0
Residue, % vol	1·0
Loss, % vol	Nil
Flash point closed, °F	120
Viscosity at 100° F, cS	1·40
Pour point, °F	−50
Cloud point, °F	−52
Cold test, °C	−43
Inorganic acidity	Nil
Organic acidity	Nil
Carbon residue (on 10% residuum), % wt	0·02
Total sulphur, % wt	0·041
Water	Nil
Sediment by extraction	Nil
Water and sediment	Nil
Cetane No.	45 approx
Corrosion Cu-strip (3 hr at 50° C)	Passes
Smoke point, mm	31
Char value, mg/Kilo	11

Grease. The generator bearings are packed for life at the factory of the manufacturers, and it was agreed that these bearings should be packed with a grease conforming to the DTD 783 specification.

OTHER PROBLEMS ASSOCIATED WITH PETROLEUM PRODUCTS

Fuel for Heating and Cooking

The choice of regular-grade kerosine for this duty was based partly on a desire to use a common fuel for heating and cooking and as a diesel fuel, and also in the knowledge that fairly good low temperature properties would be required, although it was understood that the diesel fuel supplies would be stored in a reasonably warm location. In addition, it was accepted that this fuel when used for cooking when travelling should be kept in small containers in a warm location in the vehicles in order to prevent solidification. Inspection data on the kerosine used are given in Table XIV.

Petrol stoves were definitely unacceptable to the Expedition. A supply of methylated spirits was provided for initial heating of the primus stoves.

Fuel for the Oil-burning Engine Preheater

The oil-burning heaters, with which it had been decided to equip the petrol-engined transport vehicles (Sno-Cats and Weasels), to make starting possible under extreme cold conditions, were originally designed to operate in temperate climates on kerosine. Two types of fuel were supplied by The British Petroleum Co. Ltd for the Expedition, kerosine for the diesel engines and for domestic heating and cooking, and a special high vapour pressure gasoline for the petrol engines. The Expedition authorities required to know if the heater could operate on motor gasoline, partly as a matter of policy in conserving the heating and cooking kerosine supplies, and partly because the use of kerosine for the engine heaters at low temperatures, about −60° F, would be ruled out because of its pour point of −50° F.

During the cold chamber test of a Sno-Cat vehicle at an ambient temperature of −67° F, just prior to the departure of the Expedition's advance party in November 1955, considerable difficulty was met in maintaining stable combustion in the heater when operating on the gasoline. There was insufficient time available for any development work to be carried out on the heater, which was fitted in its standard form, and it was agreed that the BP Research Centre should examine the problem and attempt to have a solution by the time the Expedition ship arrived in Montevideo.

Since operational requirements of the Expedition restricted the number of types of fuels that could be transported, tests were made with blends of kerosine and high vapour pressure gasoline in an attempt to find a suitable mixture which would give a reasonable combustion in the heater over the required air temperature range, namely, −10° to −70° F. Work on this appliance was carried out in the large Rotax cold chamber at Hemel Hempstead and in smaller cold boxes at the BP Research Centre down to temperatures as low as −70° F. As a result of this work, it was concluded that satisfactory combustion could be obtained in the heater at ambient temperatures from −70° to −10° F when using a kerosine/high vapour pressure gasoline blend in the ratio of 2 : 1 by volume.

Methanol for Preventing Filter Icing in Vehicles

Methanol was supplied for addition to the vehicle tanks in the proportion of approximately 1 pint of

methanol per 15 gallons of motor spirit where necessary. This gave a separated lower layer which did not freeze and could be drained off and gave protection against possible fuel line and filter blockages due to adventitious water, *e.g.* condensation, driven snow, etc.

Other Materials

Light instrument oil for instrument lubrication, white spirit for use as paint thinners, anti-seize grease for spark plug threads and propeller mating splines, and pitch for boat caulking were also supplied in small quantities.

Containers

For ease of handling, all fuel and lubricant requirements for the Expedition, excluding bunkering and marine lubricants, had to be placed in suitable containers, and for this purpose 45 (Imperial)-gallon drums, 40-gallon drums, 5-gallon drums, and 4½-gallon jerricans were used.

All aviation and automotive gasoline, diesel fuel, and kerosine was supplied in either 40- or 45-gallon drums, and as far as possible jerricans were used for all lubricating oils. In addition, 1-lb tins, 5-lb kegs, ½-pint, 1-pint, and quart cans, and 5-gallon drums were used to carry more than 30 different products.

All containers had to withstand temperatures down to −90° F for prolonged periods, and to test their suitability various specimens were stored in the stratospheric cabinet at BP Research Centre for periods up to three weeks with temperatures ranging from +14° to −76° F.

The use of soldered joints in any containers was avoided where possible, as it was known deterioration of these would occur at low temperatures.

The 40- and 45-gallon drums were constructed from 16 gauge mild steel with all seams fully welded, and each fitted with one 2-inch and one ¾-inch two-nock Trisure bungs both situated in the head.

Tests were also carried out to investigate the properties of both jerrican and Trisure washers at low temperatures and although both types hardened considerably after prolonged storage at −76° F, they showed no physical defects and provided satisfactory seals.

The 5-gallon drums were constructed from 22 gauge mild steel, double seamed and welded, complete with 2-inch Trisure flanges and steel bungs.

The jerricans were of normal pattern suitable in all respects for the conveyance of petroleum products and fitted with synthetic washers.

The suitability of various internal and external paints was investigated, and as a result it was decided that the interior of the 40- and 45-gallon drums should be of a milled finish, and those of the jerricans in a petrol-resisting paint.

Externally, all drums were finished with suitable resistant paint and colour coded for easy recognition. The 40-gallon drums were finished in red for motor gasoline, blue for aviation gasoline, and black for kerosine, and the 45-gallon drums for motor gasoline aluminium colour. Jerricans were finished in olive drab with coloured strips to indicate the product contained.

Estimated quantities of those containers used are:

45-gallon drums	.	460
40-gallon drums	.	1040
Jerricans	.	400
Other packages	.	200 (5-gallon drums, small cans, and grease kegs)

BEHAVIOUR OF FUELS, LUBRICANTS, AND GREASES IN ANTARCTICA

Transit to Antarctica

The fuels, lubricants, and greases for Shackleton Base were transported from the Port of London to the Antarctic by ship. The first load was taken down in m.s. *Theron* in November 1955, and the second in m.s. *Magga Dan* in November 1956. In both cases the fuels were in 40- and 45-gallon drums and travelled as deck cargo.

The length of the voyage was just over 9000 miles, and the ship rolled heavily. Some of the storms encountered caused rolling to a maximum of 47°, and would thus cause considerable fuel movement inside the drums. The temperatures encountered upon this stage of the journey would be from a November, London, ambient temperature, through the tropics (which would have been around 110° F maximum) to the Antarctic—below freezing point.

Antarctic Storage

All fuels, lubricants, and greases were off-loaded from the ships and conveyed by sledge to the fuel storage area, where they were set out in long lines in the snow. There they remained for the winter through the conditions shown in Fig 1 of temperature and wind. The lowest temperature experienced during the winter of 1956 was −63·7° F, and during the winter of 1957, −71·2° F was reached.

Use of Petroleum Products at Base

Climate. The trend of wind and temperature is clearly seen in Fig 1. The combination of low temperature with wind, called wind chill, is the really important factor, for, other things being equal, it is this which controls the effectiveness of the human being in the field.

The most severe weather was certainly experienced at base and this, combined with winter darkness, made operations very trying. The advantage of having a heated base and workshop was clearly seen when repair work was necessary. All refuelling and topping up of oil was performed out of doors, and it

would be reasonable to expect far more trouble than in fact was experienced. With the correct materials and strict attention to operational detail, field work can be successfully carried out.

Vehicles. In March 1956, during a blizzard, one Ferguson tractor was lost when the sea ice broke up.

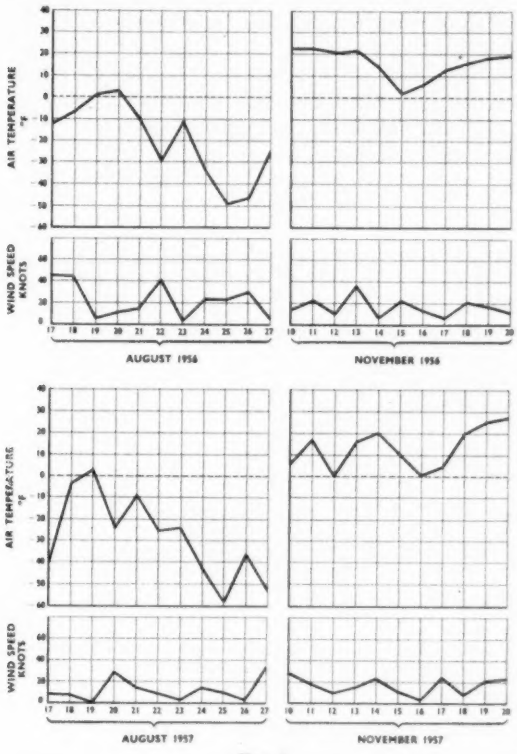


FIG 1

WIND AND TEMPERATURE CONDITIONS AT SHACKLETON BASE IN AUGUST AND NOVEMBER, 1956 AND 1957

Provisional presentation of data. Snap observations.

All vehicles were used prior to the departure from Shackleton. In autumn and winter 1956, one Sno-Cat, two Weasels, and one Ferguson were in use, and in the second year the balance of the transport, consisting of three Sno-Cats, two Weasels, and one Muskeg tractor were operative. Up to the time of the departure from base approximately 3200 vehicle miles had been run.

The startability was always excellent. In fact, a Ferguson at −40° F, after being hand-cranked for twelve revolutions, was successfully started with batteries which were too low to turn over the engine. During the last winter, a heavy workshop programme on all vehicles was executed which entailed many modifications. Finally, each vehicle was started and operated successfully at −60° F.

Diesel Generator Sets. The diesel fuel (kerosine) was entirely satisfactory, although in the winter it did on occasions gel and had to be thawed out inside the hut. The first 500-hour and subsequent 1000-hour de-cokes showed no undue carbon.

The crankcase lubricating oil was quite satisfactory, but owing to storage outside it always had to be thawed before it would pour from the can.

Aircraft (with the Crossing Party). The Auster aircraft was first flown from the ship. It was used with floats, being lowered over the side of the ship for take-off from pools in the pack ice. Ice reconnaissance in conjunction with the ship's navigation was its primary purpose. On arrival in the Antarctic, the Auster was converted to skis and used successfully for local reconnaissance and support.

Oil dilution was always used and starting effected with the Coffman starter. Below approximately −20° F engine preheating with a Hermann Nelson heater of 400,000 B.t.u/hr output was found necessary. The Auster gave some 100 hours of trouble-free flying before it was finally crated and returned to the U.K.

The Otter was fitted with skis and used only on snow. Numerous reconnaissance flights were carried out, and it was also used as a cargo carrier for the purpose of establishing the inland station, South Ice. This was situated at an altitude of 4430 feet and was a straight-line flight of 280 miles. After the initial reconnaissance, 19 cargo-carrying flights were made and cargo totalling 19·7 tons in weight transported. Several of these flights entailed landing in high drift conditions with a visibility of 20 feet. The engine was always satisfactory, and no icing occurred in the fuel system.

In the winter, prior to crossing the continent, the aircraft was tethered and the rudder removed for safe keeping. The engine components were inhibited as follows:

1. Exterior treatment of engine with lanolin resin DTD 663A.
2. The interior of the cylinders was treated with inhibitor oil DTD 791B.
3. The fuel system was treated with anti-freeze oil DEF 2001.
4. The oil tank interior was treated with storage oil DTD 698.

In the spring its condition was excellent except for fine drift snow which had penetrated inside the wings, and the first test flight gave no trouble.

On 6 January 1957 the Otter, which had already moved to South Ice, took off and flew via the South Pole to Scott Base, a distance of some 1200 nautical miles, in 11 hours 20 minutes. The total capacity of the Otter during the flight (including long-range tanks) was 350 gallons, and some 300 gallons were used. This notable, single-engined aircraft flight was trouble-free from a technical viewpoint, and brought the total flying time of the Otter to some 400 hours.

Aircraft (with the Ross Sea Party). This Auster was used for reconnaissance and support and gave no trouble. Flying continued throughout the winter in order to study flying conditions and to observe ice movement in McMurdo sound. Penguin and seal colonies were also studied. The Auster flew 34 hours, mainly on minor tasks.

The Beaver was used on skis, flying from snow or ice throughout. It carried out the invaluable task of flying in all the stores required by the crossing party. This entailed the stocking of five depots, the highest of which, Depot 700, was at about 9000 feet, and the aircraft always had to climb to 12,000 feet to clear the mountains. A total of 266 flying hours were performed without trouble.

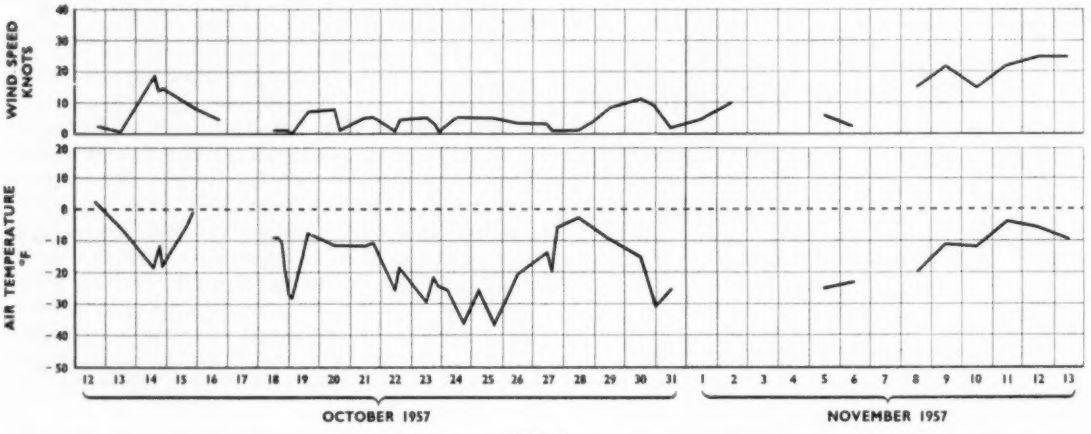


FIG 2

WIND AND TEMPERATURE CONDITIONS FOR THE FIRST SOUTH ICE JOURNEY FROM 190 TO 4430 FEET
No maximum or minimum temperatures recorded. Provisional presentation of data. Snap observations.

The aviation petroleum products were trouble-free and gave excellent performance. It is worth noting that refuelling was always carried out most carefully and a stringent filtering technique enforced. About half a teacup full of ice crystals and sediment was removed from the pressure filter after pumping each 120 gallons. In fact, no trouble was encountered from this ever-present danger. Two U.S. Dakotas force-landed in the area due to ice in the fuel lines.

Reconnaissance Journey to South Ice

Although the conditions are better in summer, there is a great difference between base operations and trail journeys from the human aspect. Personnel are living continually out of doors, and must discipline themselves to even stricter attention to maintenance, refuelling, lubrication, and greasing.

The first inland journey from Shackleton was undertaken to find a route from the ice shelf up on to the inland ice cap. The journey started late because of bad weather, and many attempts had to be made to cross the heavily-crevassed glaciers. The first of the two glaciers presented an 11-mile stretch of crevasses, the worst mile of which had 98 marker flags, each indicating a severe danger point. The party, consisting of one Sno-Cat and three Weasels, took 39 days instead of 14, as planned, to cover the distance of 390 miles. The heavily-crevassed country was the main cause of this delay, and although mechanical breakdowns were experienced they were not associated with the fuels and lubricants. One Weasel returned to base after shearing a top guide roller shaft. One was abandoned due to failure of a big end. In this case, when the oil pressure had dropped from 40 to 5 p.s.i., the oil was changed from Sub-zero 5W to SAE 10W in an attempt to raise oil pressure. This vehicle was driven to destruction in the hope that it might reach South Ice, since the operation of two vehicles alone in such regions leaves no safety factor. It travelled 264 miles before final breakdown.

The Main Journey

After the successful completion of the reconnaissance, it was possible to set out on the main journey across the continent. On 24 November 1957 three Sno-Cats, two Weasels, and one Muskeg tractor left Shackleton for South Ice on the initial stage of the 2250-mile journey. After traversing the heavily-crevassed sections, South Ice was reached without the loss of any vehicle. From South Ice the expedition set off on Christmas Day with a convoy of four Sno-Cats, three Weasels, and one Muskeg. Each vehicle started with full tanks, while 109 drums of motor gasoline were loaded on the sledges, a total weight of about 22 tons. The journey was completed on

2 March after travelling for 99 days. Four Sno-Cats arrived at Scott Base, the other vehicles having been abandoned according to plan as their task of acting as mobile refuelling stations was completed. The total vehicle mileage for the crossing itself was approximately 12,270.

It is difficult fully to appreciate the effects of low temperature and wind on the human body and the attitude of mind to normal tasks unless personally experienced. It is of the utmost importance that great care be taken with refuelling operations, and that all fuels, lubricants, and greases are given a fair chance to do their job. This implies the strictest discipline in maintenance.

tanks to remove the water–methanol mixture would have been a very unpleasant task.

Carburettor icing was experienced on several occasions, and it is concluded that cross-winds were assisting track-thrown snow to enter the engine compartment, thus increasing humidity. Normal carburettor icing could then take place where it built up inside the main jet venturi and in some cases even on the outside surfaces of the carburettor.

Vapour locking was a serious problem at altitude. This affected the Weasels and Sno-Cats. The cause of the severe vapour locking was the high temperatures of the fuel in the fuel system and was, of course, accentuated by the volatile nature of the

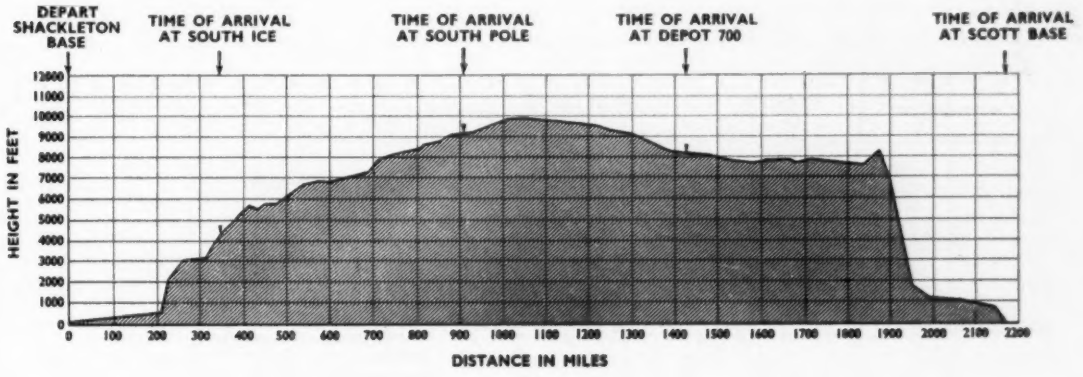


FIG 3

SURFACE PROFILE OF ANTARCTICA ON EXPEDITION'S ROUTE

Provisional presentation of data

The performance of the motor gasoline in the field proved very adequate, and this fuel gave exceptional startability under all conditions.

Some trouble was experienced because the motor fuel drums contained rust, and as the drums were new this must be attributed to corrosion arising from the presence of dissolved water and oxygen in the gasoline. This rust was particularly inconvenient when fuel was in short supply, as the barrel dregs had then to be filtered through chamois leather, which blocked very quickly. Fuel pump filters had also to be cleaned every maintenance day. These difficulties emphasize the need for the use of a corrosion inhibitor in barrelled gasoline stocks for conditions such as these.

No anti-icing additive was used in the gasoline. One jerrycan of methanol was carried in case of trouble. No fuel line icing troubles were experienced because all tanks were refuelled at the end of each day's run, thus minimizing any possible condensation from the air space. The success of this procedure was particularly gratifying, as the periodic draining of

fuel supplied. In the Weasels the high fuel temperature occurs because the engine is fully encased, so that the whole fuel system receives much heat from the engine. This, combined with an altitude of 8000 to 10,000 feet (see Fig 3), encouraged vapour locking, especially with a volatile low temperature gasoline. The fitting of heat shields overcame the problem in the case of the Sno-Cats. It can be seen in Fig 3 the large proportion of the journey which was carried out above 7000 feet.

Fuel consumption varied considerably. The Sno-Cats gave from 0·8 to 2 m.p.g. This gives a $2\frac{1}{2}$ variation factor, which emphasizes the difference in terrain and snow surface. The mean overall consumption figure for three of the four Sno-Cats was 1·54 m.p.g., and this compares not unfavourably with the planned figure of 1·4 m.p.g.

These figures are for the vehicle under load. The Sno-Cat carried a vehicle load of one ton and hauled two sledges with $2\frac{1}{2}$ tons on each.

The Weasel's overall mean consumption figure was

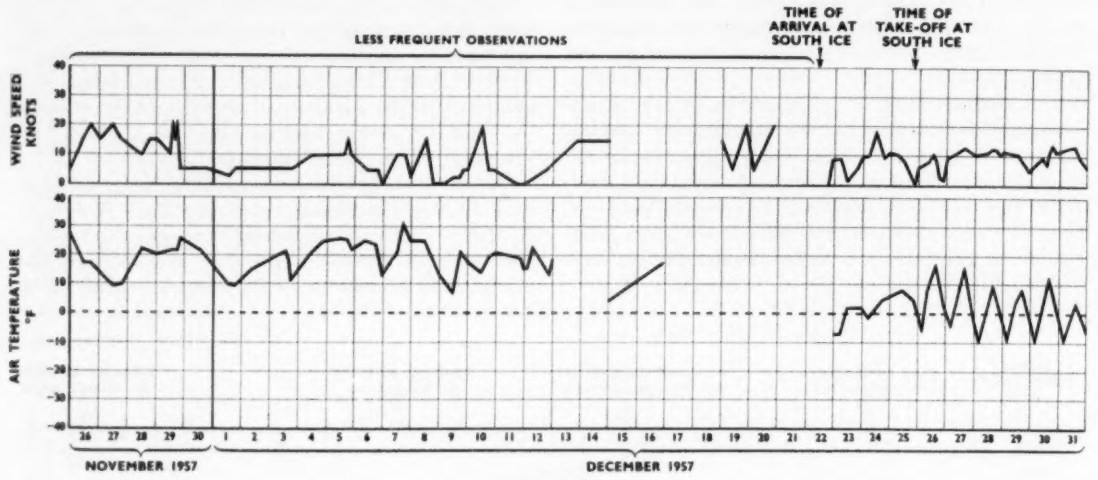


FIG 4

WIND AND TEMPERATURE CONDITIONS FOR THE ANTARCTIC CROSSING

Provisional presentation of data

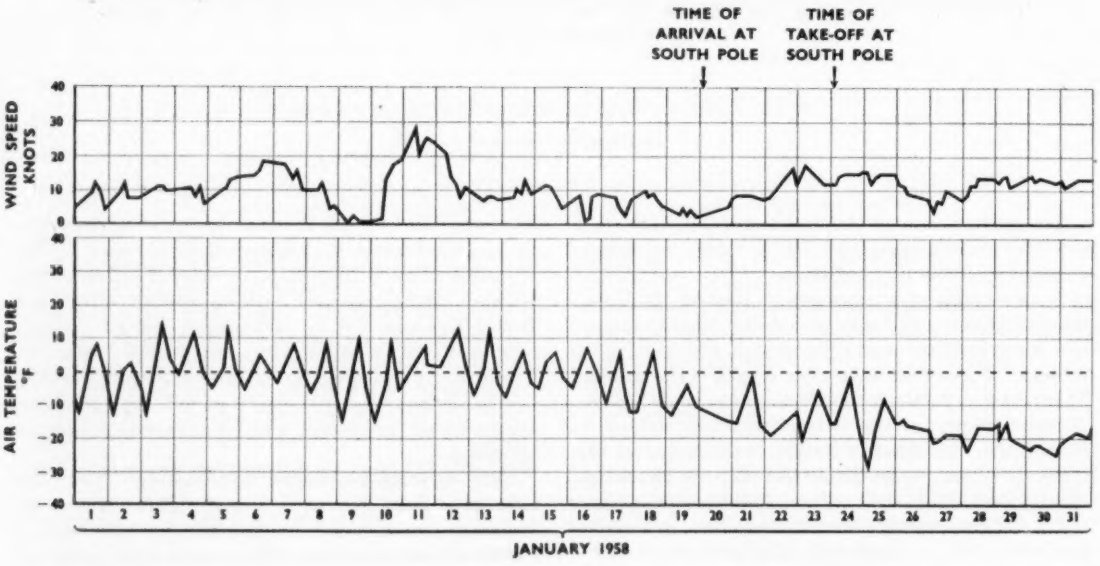


FIG 5

WIND AND TEMPERATURE CONDITIONS FOR THE ANTARCTIC CROSSING

Provisional presentation of data

1·51 m.p.g. and the load hauled was 2 tons with 1200 lb, inside the cab.

The crankcase oil proved very satisfactory with the Chrysler engine, and the consumption for the Sno-Cats improved from a test figure of 127 m.p.g. obtained in Norway prior to sailing, to a mean figure of 332 m.p.g. on the Polar journey. The actual consumption varied from 308–405 m.p.g. The Weasel engines did not compare favourably. The lowest consumption was 176, the highest 92 m.p.g. Oil in each box and one box to each Sno-Cat, making a failure of one out of 24 bearings in the transfer boxes.

The surface traverse (Fig 3) shows the gain of altitude with distance. In general all slopes were gentle. The Skelton Glacier descent, which appears as the last large descent is approximately 7000 feet in 90 miles. There were a few short slopes of about 1 in 4. Much of the journey was carried out at an altitude of between 7000 and 9000 feet. Maintenance days were religiously adhered to at approximately every 200

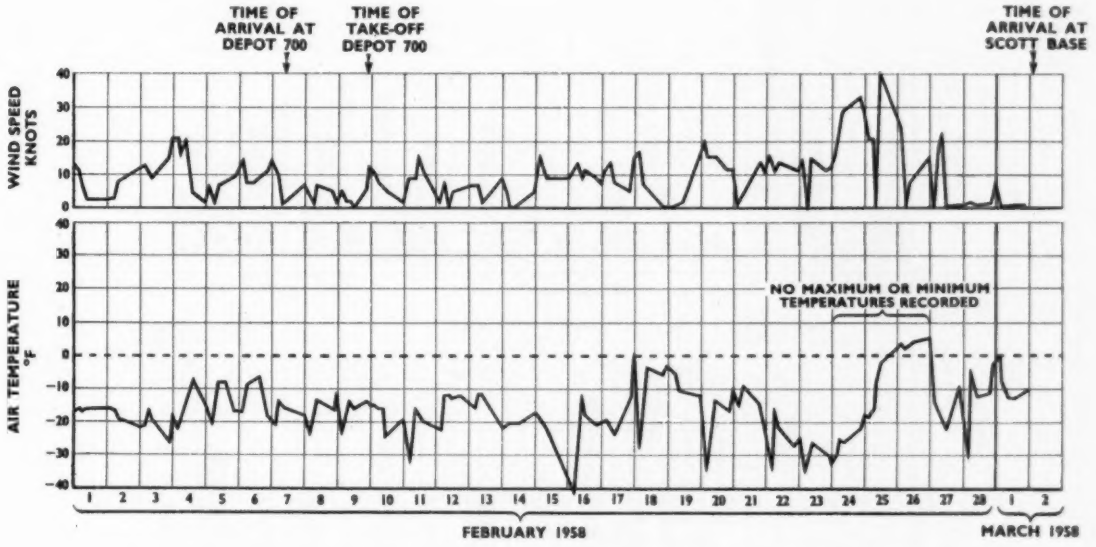

TIME OF ARRIVAL AT DEPOT 700
TIME OF TAKE-OFF DEPOT 700
TIME OF ARRIVAL AT SCOTT BASE
WIND SPEED KNOTS
AIR TEMPERATURE °F
NO MAXIMUM OR MINIMUM TEMPERATURES RECORDED
FEBRUARY 1958
MARCH 1958

FIG 6

WIND AND TEMPERATURE CONDITIONS FOR THE ANTARCTIC CROSSING

Provisional presentation of data

pressure readings on the Sno-Cats remained normal throughout.

The gear oils were proved satisfactory, as no gear box defects due to lubrication were experienced.

On the Weasels this thin oil was thrown through the gear box ventilator which required modification.

The hydraulic oil proved entirely satisfactory, and no topping up was required throughout operations in Antarctica.

The grease did its job well, especially with regard to the Sno-Cat rollers, but three outer pontoon bearings did break up. These bearings were pre-packed and were very possibly overloaded in use. One pre-packed input-drive-shaft transfer gear box bearing broke up completely, but this was the only transfer box to give trouble. There are six of these bearings

miles and it can be seen (Fig 7) that where possible, some mileage was made even on a maintenance day.

From a polar point of view the meteorological conditions were not unreasonable. The field terrain conditions were at times severe and much has been learnt technically. Detailed planning and preparatory work assisted the final result. The Trans-Antarctic Expedition reached Scott Base on 2 March 1958 after 99 days of travelling on this 2200 mile journey.

ACKNOWLEDGMENTS

The authors are indebted to the Committee of Management of the Trans-Antarctic Expedition and to the Chairman and Directors of The British Petroleum Company Ltd for permission to publish this paper.

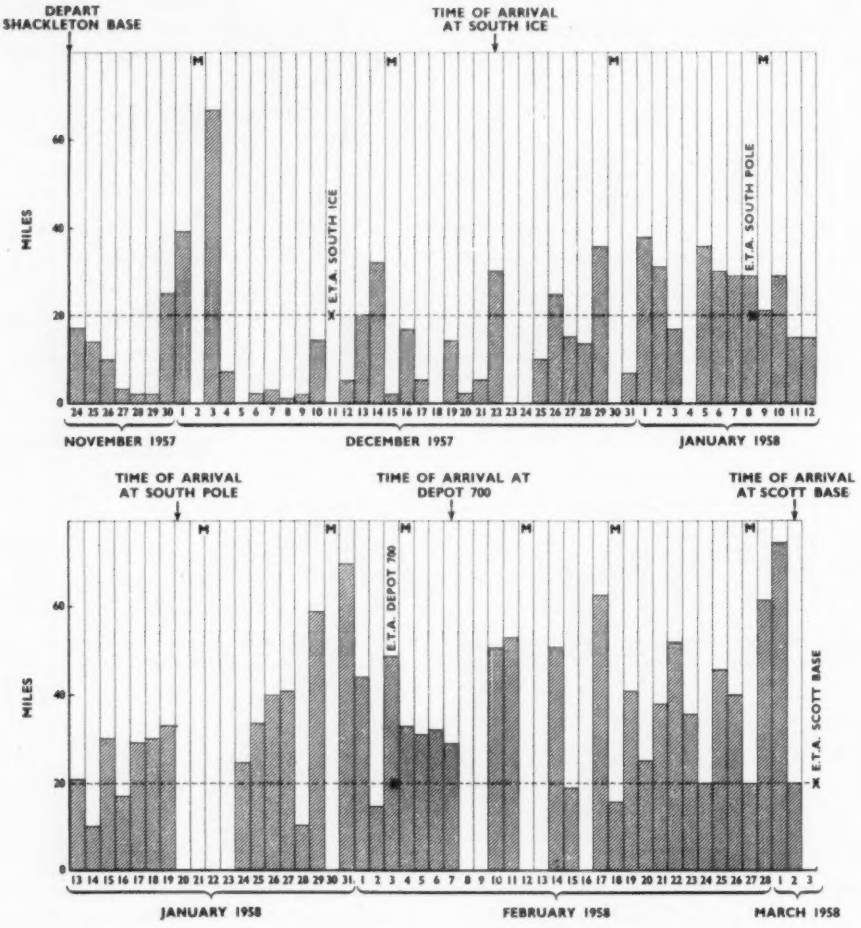


Fig 7

DAILY MILEAGE FOR THE ANTARCTIC CROSSING, SHOWING ALSO NORMAL MAINTENANCE DAYS (M)

Provisional presentation of data

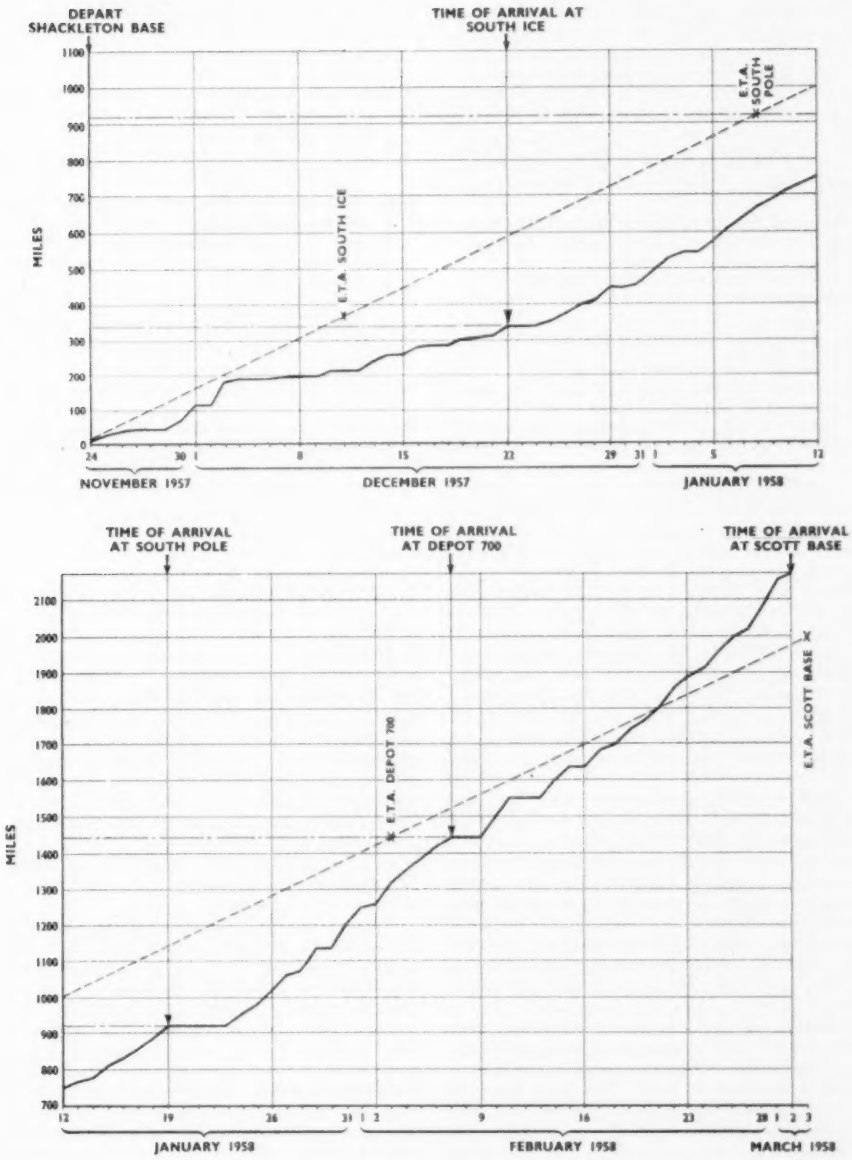


FIG 8

DISTANCE–TIME PROGRESS CHART FOR THE ANTARCTIC CROSSING

Provisional presentation of data

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DISCUSSION

J. D. Davies: I think that those of us who have followed this expedition from day to day would all like to express in public our very great appreciation, and the sense of awe and admiration for the party who undertook the expedition. I particularly welcome the opportunity to-night of being able to do this, and I am sure I am echoing something which is in all of your minds.

When an expedition such as this one comes back, they lose no time in paying tribute to those who have forged the way for them and provided the experience on which their success has been built. I am quite sure that this tribute is paid in no sense of false modesty and that it is a genuine expression of their dependence upon those who have done these things before. I think particularly in this respect that the paper to-night will be of immense value and importance in future days for those who undertake such expeditions. So that apart from the general interest of this paper, which is very great to all of us, the authors must be congratulated, and will be thanked by those who follow after, for the very real value of the contents.

I found, in reading the paper and listening to the very interesting lecture, that there was something characteristically British about it. I do not want to underestimate the immense amount of work that went into the modification of equipment, but one did feel that the characteristic British quality for improvisation and adaptation came out to the very full in the wonderful work that was done. The enormous care that has to be taken in detail and planning is the thing which I think is most outstanding in my mind. As a purely armchair observer, I find it very difficult to cross swords on any of the technical points, which were obviously gone into with great care and attention by all the persons concerned with the planning. However, from the armchair one cannot help speculating on some of the points which are mentioned in the paper.

Bearing in mind the desire to keep down the number of grades of products to the very minimum, I did wonder whether the possibility of covering the requirements of the aircraft and the tracked vehicles with a single grade of fuel was considered and eliminated as being quite out of the question. So far as the octane considerations for such a fuel are concerned, I think those would very readily be met in a single product for both types of equipment. The main difference, I think, between the two products was in front end volatility. I believe the motor gasoline showed a Reid vapour pressure of 14 lb. as against something like 6 lb for the aviation gasoline. Perhaps one might have been able to achieve some compromise, bearing in mind that starting aids and heating equipment had to be installed in order to permit hand starting in the tracked vehicle petrol engines. I would like very much to hear whether this possibility was considered and discarded.

There was also reference to the choice of petrol engines for the vehicles as opposed to diesel engines. I must confess that when I read the paper I suspected that the main reason for this was probably one of cost. These vehicles were in existence and probably it was cheaper to stick to gasoline engines. Undoubtedly there were also considerations, as we have heard to-night, of operation at low temperatures—particularly starting. However, I would have thought that the attraction of the very much lower fuel consumption of the diesel engine would have warranted serious consideration of its use. It does occur to me that possibly the apparent attraction is not quite so real in the case of this Trans-Antarctic journey. In normal transport operations the diesel offers a very substantial saving in fuel consumed compared with the gasoline engine. Perhaps under these conditions, where I imagine that the load factors of the vehicles would be very high, the difference in fuel economy might be much less. I would like to know, having had no personal experience of trying to operate vehicles at a temperature of −60° F, whether the problems with diesels are quite insuperable when one has coolant water heating and other starting aids?

D. L. Pratt: Considering the possibility of wishing to interchange fuels in the field due to emergency or supply shortage, I did ask the British Petroleum Company to investigate this matter and would like Mr Lodwick to deal with the question of a single fuel. I would just like to state that, when in the Antarctic, the product must be right, or capable of being put right. If anything goes wrong, is too complicated, or will not work, then it must be remembered that there is no chance of outside assistance.

As to the choice of diesel *v.* petrol, I have a few comments. The compression ratio of a diesel engine is around 19 : 1—that of a petrol engine from, say, 6 : 1 to 8·5 : 1. Now let us consider the worst case, when all starting aids, such as preheaters, glow plugs, and auxiliary starting engines have broken down. It is clearly easier to turn over and start the engine using the more volatile fuel with the lower range of compression ratio.

As to the possibility of using diesel engines in the Sno-Cat, I did have the opportunity to get diesels, but generally speaking the basic engine weight of a diesel is greater than that of a petrol engine. Whilst in North Greenland with the Americans I saw them using D8's. You probably know the huge 30-ton tractors, which, incidentally, are expensive, costing some £30,000, as against the Sno-Cat cost of £5000. A Sno-Cat weighs four tons and the difference between the two when crossing a crevasse is very obvious. We had to have a light vehicle train in the first instance. If one has four D8's there are 120 tons of vehicle weight on the move without even considering the load on tow. I agree that one can tow a lot, but I do not think D8's would cross our sort of terrain. However, we could have had diesel engines for the Sno-Cats, but I still think the starting problems are very much more severe. I personally have tried to start our 6-kw diesel generators at −10° F without starting aids and failed. I would not have liked to have had diesels in those Sno-Cats. I knew that we could always start them without a preheater, even down to −40° F, and I have personally hand-cranked and started a Ferguson at −40° F with low temperature batteries. The batteries would not turn the engine over, but after loosening up the engine by standing on the starting handle and getting it round twelve times and then switching on, a successful, if lucky, start was made. One could never achieve that with a diesel in any circumstances. I think with a heavier vehicle train I personally would choose diesels. The Americans, when they make their Byrd Station journeys in the Antarctic, use D8's, D6's, and D4's. They haul three 10-ton sledges behind each and they have a 24-hour rota system and never stop the engines. I am afraid we would have used much fuel by keeping the engines running in crevassed terrain. Hence we wished to be light and mobile and to guarantee startability.

J. R. Lodwick: Dealing with Mr Davies' question concerning the use of motor gasoline as an aircraft fuel, it is well known that there are very stringent rules relating to the quality of aviation gasoline. The use of a very volatile motor gasoline would have been an unnecessary hazard when used in aircraft. The other alternative, of course, would have been to use aviation gasoline in the motor vehicles. This would have been quite feasible, but the startability characteristics would not have been satisfactory. This could have been overcome by supplying two grades of fuel: a volatile gasoline for starting, and then the aviation fuel for normal operation.

The Expedition authorities, however, did not wish to complicate matters, and I think that if one considers all aspects of the problem, their decision to use motor gasoline for the tracked vehicles and aviation fuel for aircraft was the right one. We did, of course, consider what would happen if all the aviation gasoline were accidentally lost and whether there would a reasonable chance of flying by using the motor gasoline. We considered that this course could have been followed where no other alternative existed, but it was a risk that would not be taken under normal conditions.

With regard to the part of the question dealing with the use of diesel fuel as an alternative for motor gasoline, Mr Pratt has already indicated the reasons why the gasoline engine was chosen. If a vehicle is isolated in extremely cold weather there is a very good chance of starting the engine on volatile gasoline, when the task of starting a diesel vehicle under the same conditions would be hopeless.

N. P. W. Moore: We have listened to a record of courage, there is no doubt about that. We have seen the poles crossed, but they will be crossed again many times, be it for strategic or eventually economic reasons. I think this makes us hope very much that the work will go on. The first journey is over, but surely the work must continue, and would it not be appropriate to ask whether we are doing enough industrially to give engineering developments support in this sort of effort. There is the question of batteries. A tremendous amount of them must be sold throughout the year, but is enough basic work being done at these low temperatures under laboratory conditions so that the next expeditions and the economic ventures that follow them may have something rather better? Is this not perhaps the moment to take stock of what we are doing on the low temperature starting of vehicles? It is obviously important to do as much in the laboratory as possible. There cannot be many expeditions and there has to be something very much stronger than a mere technical need to go so far with so much expense. It is a tribute to British enterprise, but perhaps not entirely to British engineering, for there was a great deal of equipment which was already on the ice.

D. L. Pratt: I cannot answer for the whole of industry, but I have had dealings with ninety-six engineering firms and know that in the field of batteries much research work is taking place. Lead–acid batteries are well proven—we used them to a military specification. They were of the multi-plate, thin-plate type, and their performance was remarkable down to −40° F.

There is clearly an opening in the battery world for some field trials of nickel–cadmium, and I am advising, in a technical capacity, the Belgian Antarctic Expedition which sails in November. They are going to use nickel–cadium batteries. These, as you may know, have remarkable characteristics. They can be run flat, overcharged, discharged at peak currents, or even frozen and no damage is done.

Much work has been done, but I deeply appreciate Mr Moore's remarks, because I sincerely hope that more work will be done in the U.K. I can see that it must have a commercial, or shall we say practical, angle if it is to be carried out by industry, but I think that it should also be regarded as important for the sake of pure research. Whenever there has been a war, our allies, such as Canada, have always played their part, but it is important that the U.K. should be in a position to provide technical knowledge in such a joint effort, for the Arctic, like the Antarctic, forms a very large part of the world's surface.

The meeting then closed with a unanimous vote of thanks to the four authors.

SOME OPEN QUESTIONS REGARDING PETROLEUM ORIGIN*

By BENJAMIN T. BROOKS† (Fellow)

In several recent papers [3-6] evidence has been presented as to the probable role of natural silicate minerals acting as catalysts in the formation of petroleums. This theory harmonizes with a great many geological and chemical facts and offers, for the first time, plausible scientific explanations of many facts hitherto lacking such understanding. The accumulated evidence in support of these views is far too great to be included within the usual space limitations of published articles. However, some reference to the more pertinent now generally accepted facts and what may be called, for the sake of brevity, the catalytic theory of petroleum origin, should be mentioned in order to better understand some particular problems which are still either unsolved or are in an unsatisfactory state.

The general problem of petroleum origin can be stated to be how to account for the formation of oil and gas: (1) having the complex composition of these essentially hydrocarbon mixtures; (2) from any common type of organic matter capable of being deposited in relatively large quantities in marine sediments; (3) within the limitations set by the physical and chemical environment established by geology.

RECOGNIZED GENERAL FACTS

Certain essential facts should be briefly stated:

(1) All known petroleum source beds and substantially all reservoir rocks are marine sediments or strata.[22, 38, 40] No commercial production of petroleum is derived from any terrestrial or fresh-water deposits, although very small amounts of hydrocarbons said to resemble petroleum have been found in soil and in the mud bottoms of fresh-water lakes in Wisconsin and Minnesota, as well as in other recent sediments generally, apparently wherever organic matter is deposited under anærobic conditions.

(2) Under ordinary ærobic conditions and in the presence of moisture, all forms of organic matter, including petroleum itself, are rapidly destroyed by bacterial action. Preservation of deposited organic matter in the sediments requires anærobic conditions soon after or concurrently with deposition. This requires either rapid deposition of sediment, as has occurred in most of the important American oil-producing fields, or euxinitic conditions, as in the Black or "Euxine" Sea. Preservation in concentrated saline water has also been suggested. Most of our petroleum has been produced from the thick sedimentaries of Cretaceous and Tertiary times, and most of the world's known reserves are in the same formations, probably due to the fact that the continental land areas were greater during these times, affording abundant material by erosion for the accumulation of thick marine formations.

(3) Marine origin of petroleum source beds determines the nature of the organic matter deposited originally in these sediments. Such organic débris may have come from diatoms, foraminiferæ, plankton of various kinds, algæ, and marine animal life; all of these types contain fatty oils.

(4) The temperatures in the sediments when first deposited were necessarily those of the ocean water and are probably not very different from ocean temperature near land areas to-day; the temperatures in strata of marine origin increase as the thickness of the overlying insulating blanket is increased by continued deposition. In relatively undisturbed areas, such as the Gulf Coast, the bottom-hole temperatures now observed [6] undoubtedly represent the maximum in the entire geological history of the strata. Some geological authorities [8] have stated that 140° F represents about the upper limit in the history of most petroleums. Very deep wells, of course, show higher bottom-hole temperatures, but the relatively low temperature history of petroleum, its source beds, and reservoir rocks is now well established. This is also fully consistent with many chemical facts.[7]

(5) There is considerable statistical evidence, confirming general opinion, that petroleums change in composition during long periods of time. At any rate, geologically recent oils are generally deficient in light fractions (gasoline) and free from wax. Gas-to-oil ratios are generally higher in older formations. D. C. Barton [1] believed, from a study of the Gulf Coast oils and their geology, that these oils had originally, or at an earlier stage, been material that was "too thick and viscous to move except through open channels" and that "such material may never be found in accumulations and may have to be sought as droplets scattered through the source formation." McNab, Smith, and Betts,[25] from a wider survey of crude oils, agree generally with Barton and concluded "The

* MS received 21 July 1958.

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foregoing data indicate that there is considerable evidence of a progressive evolution in crude oils, from the heavy cyclic crudes first formed and found in young sedimentary rocks, to the lighter, more paraffinic crudes containing larger proportions of low molecular weight components and commonly found in producing horizons of great age or depth."

A later survey of Gulf Coast oils,[4] including many produced at greater depth than were available to Barton, and the data published by McNab, Smith, and Betts, show that the composition of crude oils does not vary *regularly* with age and depth, but oils of the same age and depth may vary considerably in composition, although the relationships pointed out by Barton and McNab *et al* are roughly true. There are also some very conspicuous exceptions to the general rule, *i.e.* heavy, black, asphaltic oils produced from very old formations. The conclusion is obvious that there must be another factor, other than age or depth, which determines change in crude oil composition and, as will be shown later, such variations and apparent exceptions are to be expected.

(6) Natural silicates occurring widely in shales and other sedimentary rocks exhibit properties similar to fuller's earth and other acid mineral catalysts.[8] Such catalysts cause polymerization of olefins, isomerization of paraffins and olefins, hydropolymerization, hydrogen transfer, breaking of carbon–carbon bonds, and alkylation [9, 30] of aromatics by olefins rapidly at moderately elevated temperatures. The polymerization of olefins by fuller's earth has been attributed to the acid character of the catalyst [11, 18] and carbonium ion reactions as suggested by Whitmore.[43-4] Catalytic cracking by acid mineral catalysts [16, 36] and alkylations by acid catalysts [31, 44] are also generally believed to take place through carbonium ion reactions. The acidity of certain mineral catalysts has been measured.[42] Earlier papers give more detailed discussion of the role of acid mineral catalysts in the formation of petroleum and natural gas.

FACTS PLAUSIBLY EXPLAINED BY THE ACTION OF ACID CATALYSTS AND CARBONIUM ION REACTIONS IN PETROLEUM FORMATION

(1) The complex composition of petroleum.

(2) The absence of olefins in straight-run gasoline and in alkylate gasoline.

(3) The formation of aromatic hydrocarbons at low temperatures.

(4) The formation of *cyclo*paraffins.

(5) The variations in composition of petroleums of the same age (due to differences in the character of the minerals in contact with the oil).

(6) Heavy oils of the geologically young type are found in non-catalytic limestone reservoirs such as the oils from the Arbuckle Lime (Ordovician) and certain black Wyoming oils.

(7) Oil formation could not be expected in the Green River shales by the action of an acid silicate catalyst since these shales are essentially a magnesia marl and contain much sodium carbonate; geologists state that these shales are not a marine formation but have been deposited in inland brackish water.[2]

Terrestrial deposits, such as peat and various types of coal, are derived from different types of organic source material. The idea that coal may have been converted to petroleum has been given up for purely geological reasons.[22] However, the fact that brown coal containing montan wax and cannel coal and similar coal, rich in waxy material, is stable through long periods of geologic time, is probably due to the absence of acid silicate catalytic minerals.

The above facts have not been plausibly explained prior to the development of the carbonium ion theory of the action of acid catalysts on hydrocarbons.

RELATED QUESTIONS

More information is needed regarding many aspects of the overall problem of petroleum origin. Some of these are as follows:

(*a*) The character of most of the organic matter in recent marine deposits is still unknown. The original material must be such as chemists are familiar with, and probably consists of fatty acids derived by simple hydrolysis of fatty oils. Both are relatively resistant to bacterial decomposition under anærobic conditions. There are many reasons for believing that fatty oils or fatty acids are the principal original source material.

(*b*) The chemical changes in the fatty oils or acids which can be assumed to be the principal original material are not known, particularly how they lose CO_2. Material such as adipocere has not been found in recent sediments. The fat of warm-blooded animals, after burial in soil for about 50 years, is converted to wax-like adipocere consisting largely of saturated fatty acids.[39] Bacterial decomposition of a series of fatty acid salts from acetic to stearic [24, 35] yielded only methane, carbon dioxide, and hydrogen. Hydrogen and methane are produced by anærobes directly from sugars,[41] and the formation of methane from cellulose is well known. G. D. Hobson [21] concluded that "methane seems to be the only hydrocarbon proved to be produced in quantity by biochemical activity in the laboratory." Bacteriological studies have been stimulated by increasing realization of the low-temperature history of petroleum formation, but an extensive bacteriological research conducted by C. Zobell for the API was discontinued after several years' work.[34, 45-7] Methane produced by bacterial action obviously cannot account for the formation of natural gas.

It is well known that small amounts of paraffin waxes are associated with fatty acids in many plants and are apparently derived from them by loss of CO_2, by some unknown biochemical process.[26] Diatoms were found to contain a fatty oil and 0·023 per cent of a solid wax,[10] impure hentriacontane, $C_{31}H_{64}$. In an extensive study of recent marine sediments, Trask [37] found small amounts of solid paraffins but no oil. So much has been made of the recent finding of hydrocarbons in small amounts in both marine and fresh-water muds that the recent findings of Stevens, Bray, and Evans [33] are of great interest. They state: "It is by now evident that hydrocarbons are common constituents of the organic débris buried in soils and sediments, even though in low concentrations," "These data suggest that the hydrocarbon-asphaltic systems of these marine muds and continental soils are predominantly non-petroliferous," "The *n*-paraffin hydrocarbons extracted from these soils and recent marine muds differ significantly in kind from those obtained from crude oils and a postulated source bed," "No oil as such was found in the upper 10 feet (maximum depth of the study) of the post-Pleistocene muds of the Gulf of Mexico."

Like the paraffin waxes found in plants, the paraffins found in the sediment have predominantly odd-numbered carbon atoms. Stevens, Bray, and Evans suggest cautiously that some of these hydrocarbons are probably produced biochemically. This discussion seems necessary to make clear that we do not yet know the nature of most of the organic matter left in the sediments after the initial period of bacterial decomposition, nor how this material becomes the complex hydrocarbon mixture characteristic of petroleums.

(*c*) In suggesting the further study of the major portion of the organic matter in recent sediments and geologically recent formations, it should be pointed out that Trask [37] was puzzled by the insolubility of most of this material, and Stadnikoff [32] described a solid organic material found in the sediment of a brackish lake, and after chemical study concluded that it consisted largely of polymerized unsaturated fatty oils. Also a soft solid organic material found in decaying algæ off N. Australia consisted essentially of polymerized fatty oils with a small amount of unsaponifiable matter, reported as wax. In both instances partial oxidation by air could have promoted the polymerization. Such partial and limited oxidation is clearly possible in view of the fact that sea water normally contains enough oxygen to sustain life, except in extreme euxinitic conditions.

(*d*) Apparent hydrogenation. The evident slow change from heavy oily material to more paraffinic crudes and gas, as noted above, has led many chemists and geologists to seek some source of hydrogen and some process of hydrogenation. However, this difficulty may be only apparent. Thus, in alkylation, which in some respects resembles petroleum formation, a mixture of nearly equal proportions of an olefin and a paraffin (*iso*butane) react to give the well-known alkylate, the portion boiling in the gasoline range consisting of paraffins and free from olefins. No hydrogen from an external source is supplied, but a highly unsaturated hydrocarbon material is retained by the acid, so that actually the total amount of hydrogen and carbon in the entire system remains the same. Similarly it may be pointed out that lubricating oil cuts show considerable hydrogen deficiency, *e.g.* a lubricating oil from Cabin Creek, W. Virginia, had the composition C_nH_{2n-4}, one from Baku, C_nH_{2n-10}, and one from Sour Lake, Texas, C_nH_{2n-14}. Also, in catalytic cracking, as pointed out by Thomas,[36] the formation of aromatics may take place simultaneously with the conversion of olefins to paraffins without hydrogen from any external source.

It is clearly impossible to secure the data necessary to prove or disprove the apparent increase in the hydrogen content of the entire hydrocarbon system. One would need to know the carbon and hydrogen content of the original source material and of all the oil and gas produced by a particular isolated field and the composition of the material left in the formation, as well as the amount of each. Such data do not exist, and evidently are not obtainable. It may be worth noting that by loss of CO_2 from fatty acids, approximately corresponding to the average composition for marine fatty oils,[19] the resulting olefin–paraffin mixture would have about 85·57 per cent carbon and 14·43 per cent hydrogen.

(*e*) There is no apparent explanation of why there are certain conspicuous differences in the composition of petroleums, *e.g.* why the gasoline fraction from Conroe crude contains 27·6 per cent aromatics, a maximum for American crudes, and that from Winkler crude in W. Texas only 4·9 per cent aromatics; why the light gasoline, 40° to 102° C fraction, from Winkler crude contains 61·4 per cent branched chain paraffins and 9·5 per cent normal, and that from Greendale, Michigan, contains 62·2 per cent normal paraffins and 13 per cent branched-chain paraffins; why the content of alkyl *cyclo*pentanes and alkyl *cyclo*hexanes and their relative percentages should be so different in these and also in the Midway, California, and Conroe, Texas, crudes, as shown by Rossini.[28]

(*f*) It would be very desirable to know if the "young" type of crudes, containing little or no gasoline and no wax, can be converted into crude such as an average Mid-Continent oil. Since natural acid silicate catalysts having their normal moisture content are relatively very inactive, any experimental work as to this possibility would obviously have to be carried out with a partially dehydrated, activated catalyst at temperatures substantially below those employed in commercial catalytic cracking. Petroleum naphthenes generally crack catalytically more

readily than normal paraffins and split either at the side chain or in the ring.[17] Isomerization of certain branched-chain paraffins is rapid at 150° in contact with an active silica–alumina catalyst.[20]

(*g*) Since asphaltic material is a normal component of most crude petroleums and is also found in substantial proportions in recent sediments, more should be known about its composition, chemical character, and manner of formation. Since the discovery of chlorophyll porphyrins in asphaltic oils by Treibs,[39] it has been generally believed that asphaltic substances have not been formed from petroleum oils by air oxidation, but are a primary component of petroleums. Probably this should be re-examined. It is possible that unsaturated fatty oils or acids are more susceptible to oxidation than chlorophyll or its related porphyrins. The formation of " linoxyn " by partial air oxidation of drying oils is suggestive.

(*h*) Since fatty oils and acids are the most probable original source material of petroleums, further information would be of interest as to the nature of fatty oils in various types of marine life, algæ, diatoms, foraminiferæ, plankton, and shellfish. Many fish oils are well known. This information would have some bearing on whether a particular type of marine life predominating in a particular environment could have any effect on the nature or composition of the final resulting petroleum. Although there is still a good deal of disagreement as to source beds, Illing [22] states that there is a general consensus of opinion that the Monterey shales of California are the most important source beds of many California oils. These shales show an abundance of diatoms, and it has been suggested that oil in or from these source beds has been derived from them. It may possibly be assumed that the fatty oils in modern forms of marine life are practically identical with those in the primitive prototypes, but this is obviously incapable of proof.

(*i*) There are many other factors or processes which to some degree affect the composition of petroleums, in addition to the principal process or series of change resulting in the complex mixture of hydrocarbons characteristic of petroleums. It has been known since the early work of Day and Gilpin [12] and Cram [14] that selective adsorption occurs on passing crude oils through adsorbents such as fuller's earth, light low-boiling hydrocarbons coming through first and asphaltic and colouring matter and some high molecular weight hydrocarbons being removed. Sulphur compounds and nitrogen compounds are strongly adsorbed.[13, 15, 27] More accurate work along these lines has been done since the term chromatography was invented. Small productions of very light oils, mostly gasoline, as in some places in Wyoming, and the asphalt-free crudes of Pennsylvania have probably resulted in this way.

The nature of the sulphur and nitrogen compounds in crude petroleums and the manner of their formation offer many opportunities for speculation, but such questions have little or nothing to do with the major problem. Some of the sulphur and nitrogen compounds exist in petroleums as labile, high molecular weight material of unknown nature, and are decomposed in distillation of the crudes, and this is one of the indications of the low temperature history of petroleum.[7]

It is obvious that many geologists and chemists have made important contributions to our present knowledge of petroleum origin. We now have a fairly good idea of why petroleum in commercial quantities is found where it is.

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OBITUARY

ARTHUR FREDERICK CASTLE

1898–1958

We regret to announce the death at the end of October 1958 of Arthur Frederick Castle, a member of the Institute since 1928. He first entered the petroleum industry in 1920 as an apprentice driller with Trinidad Leaseholds Ltd. After serving for eight years in Trinidad and in Venezuela, he joined the Turkish Petroleum Company as area superintendent in Iraq, returning to Venezuela in 1931 and a year later to Trinidad to eventually become assistant production superintendent for Apex (Trinidad) Oilfields Ltd.

In 1946 Mr Castle returned to the U.K. and was successively works manager and sales manager at Darwins Toledo Works, Sheffield. From 1950 until 1954 he was sales manager to British Oilfield Equipment Co. (Export), and in the latter year joined Newman, Hender & Co. Ltd. as technical representative covering oil industry requirements.

F. R. Newman writes as follows: "'Chick' Castle's death is a great loss to this company and is a matter of deep regret to the many friends he made throughout his long association with the petroleum industry."

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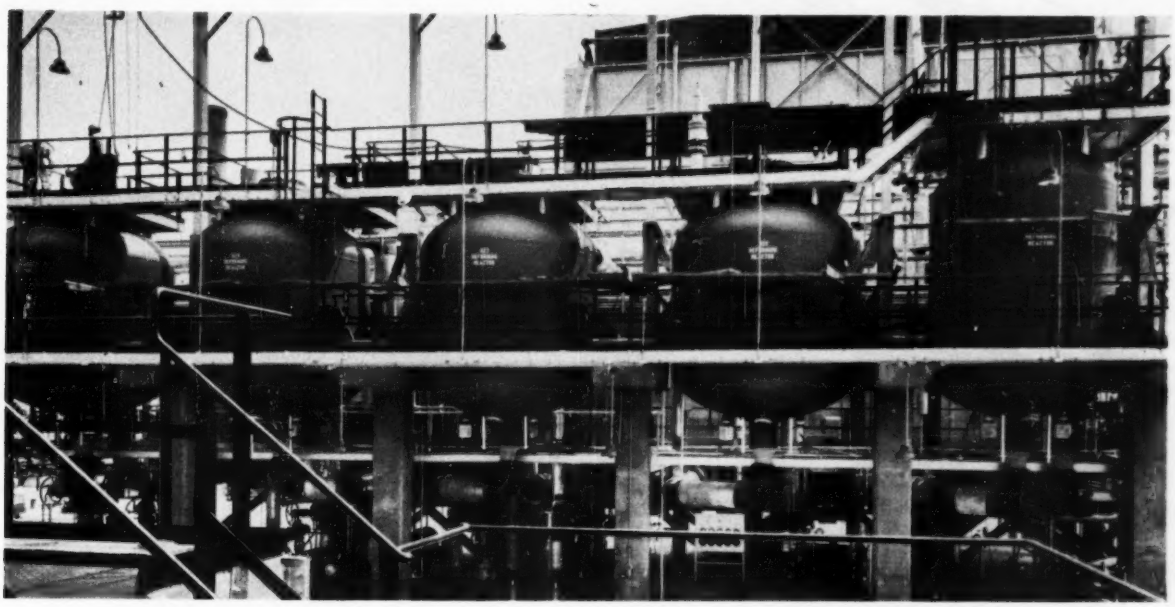

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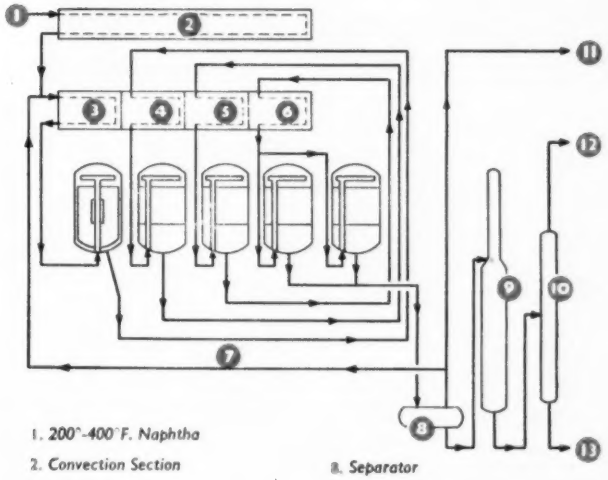

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158 ton fusion welded tower for Fawley

Shown below, in transit to the Esso Refinery, Fawley, is a 105-ton section of a 158-ton, 137 ft.-high stabilising tower fabricated by BABCOCK fusion-welding, to the order of the Lummus Co. Ltd., for Esso Petroleum Co. Ltd.

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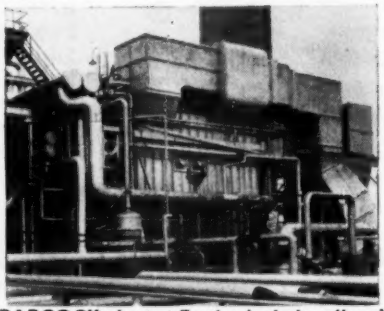

BABCOCK plant at Fawley includes oil and gas fired boiler plant. Above: one of the outdoor type FH Integral Furnace boilers.

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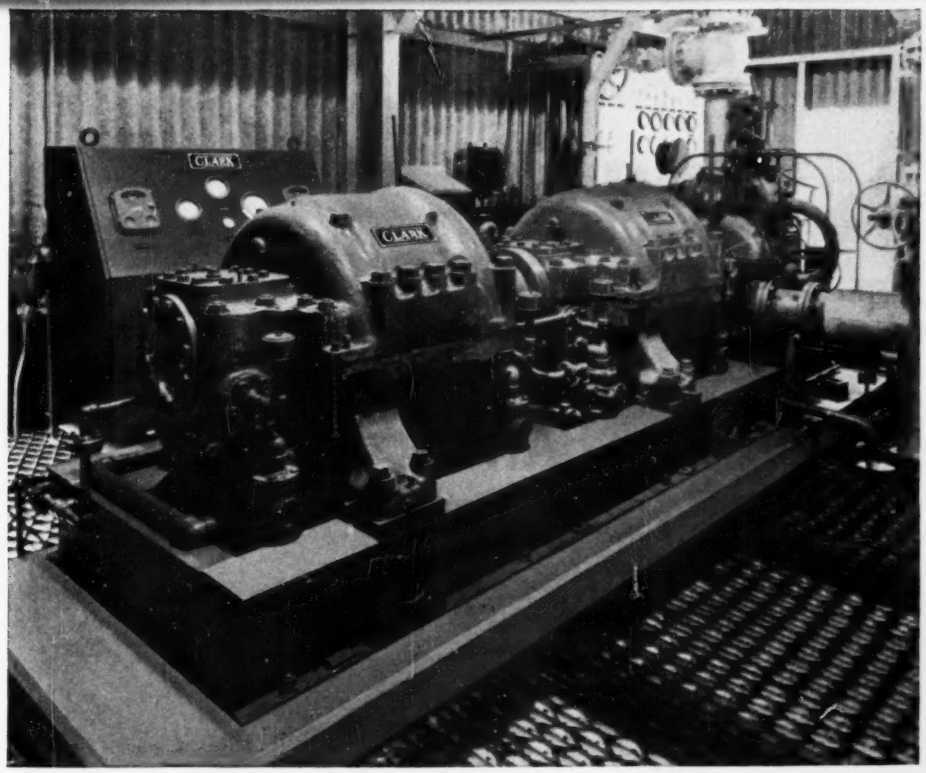

Two Clark No. 2 case 4-impeller centrifugal compressors for process gas on butene dehydrogenation duty at modern refinery of Esso Petroleum Company Limited, Fawley. Low stage 7650 S.C.F.M. High stage 7300 S.C.F.M. 9000 rpm., 1820 bhp. Driven by direct coupled steam turbine.

How Clark Centrifugals serve Esso at Fawley

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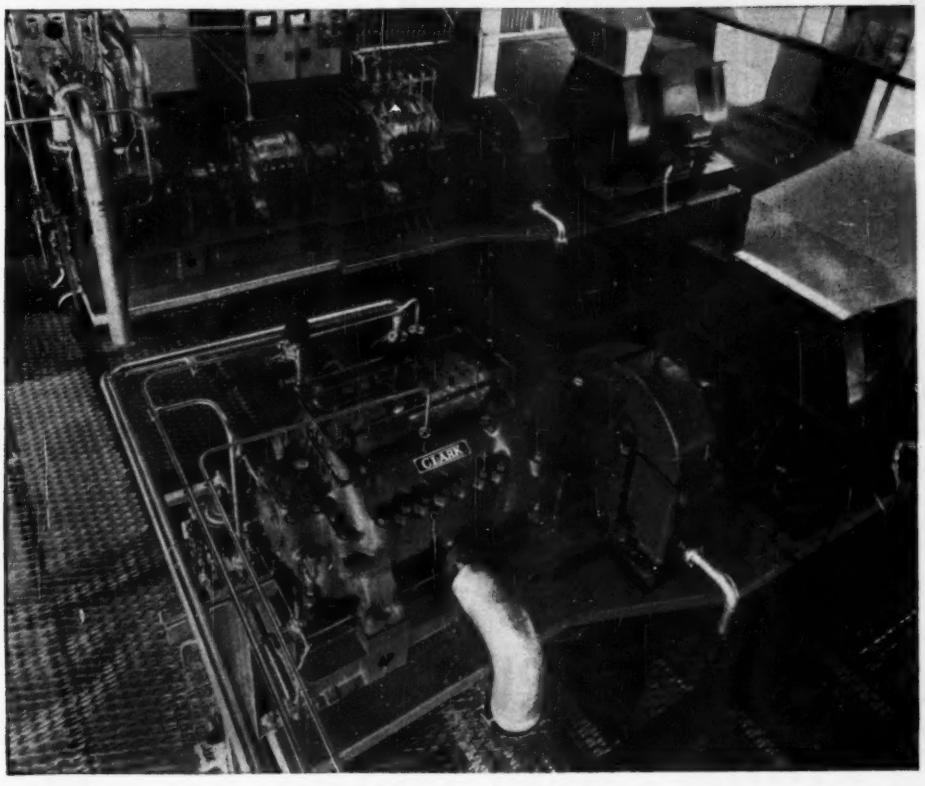

Three Clark centrifugal compressors at Esso refinery at Fawley. Driven in tandem through speed increaser gear by 3500 bhp. electric motor: 1st stage, No. 3 case 4-impeller 11,400 S.C.F.M. at 8450 rpm.; 2nd stage, No. 2 case 5-impeller 8960 S.C.F.M.; 3rd stage, No. 1 case 7850 S.C.F.M. and

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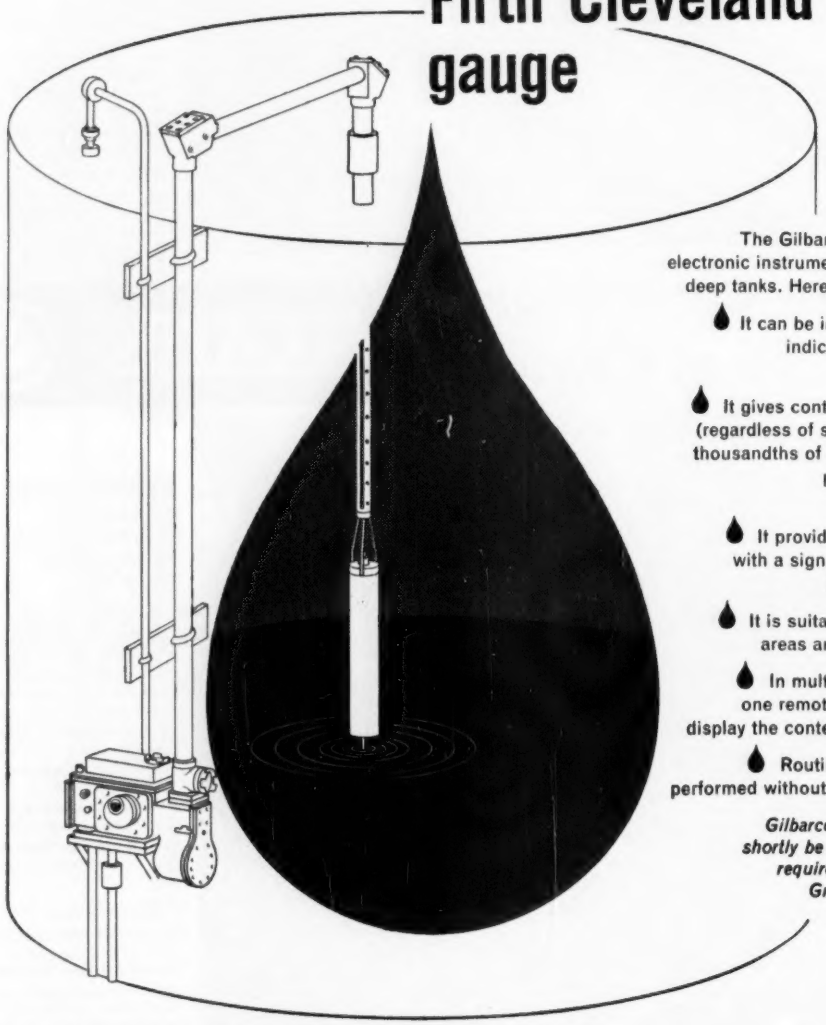
this is the GILBARCO Firth Cleveland gauge



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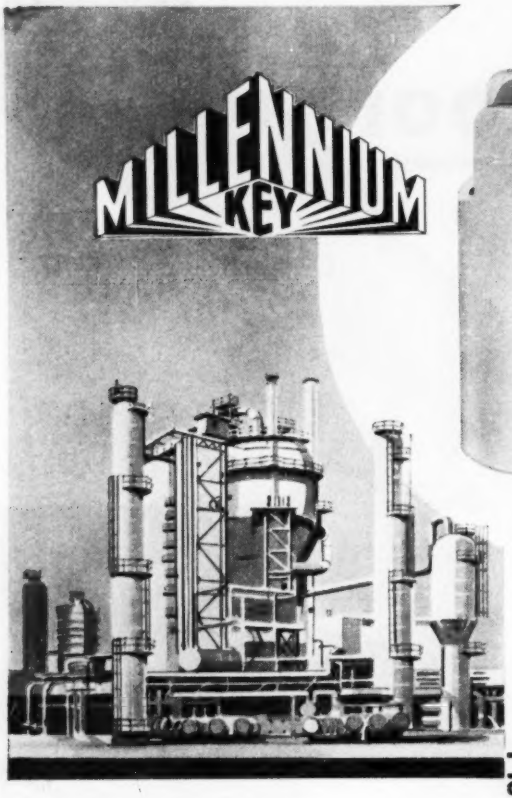

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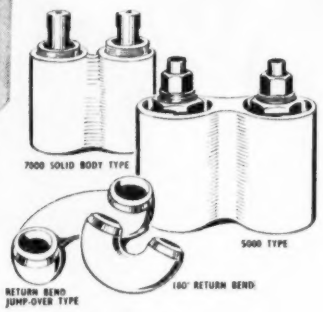

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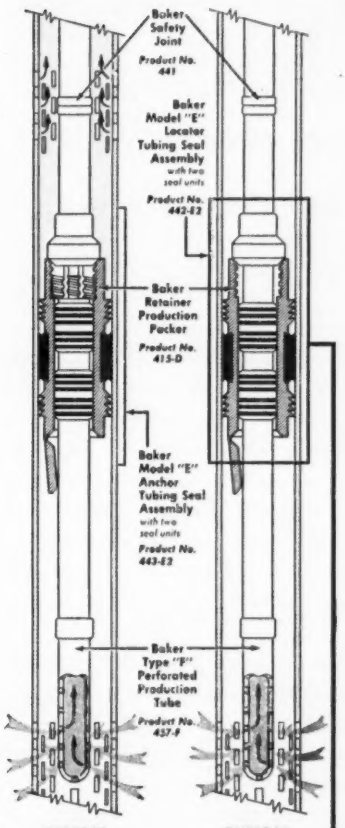
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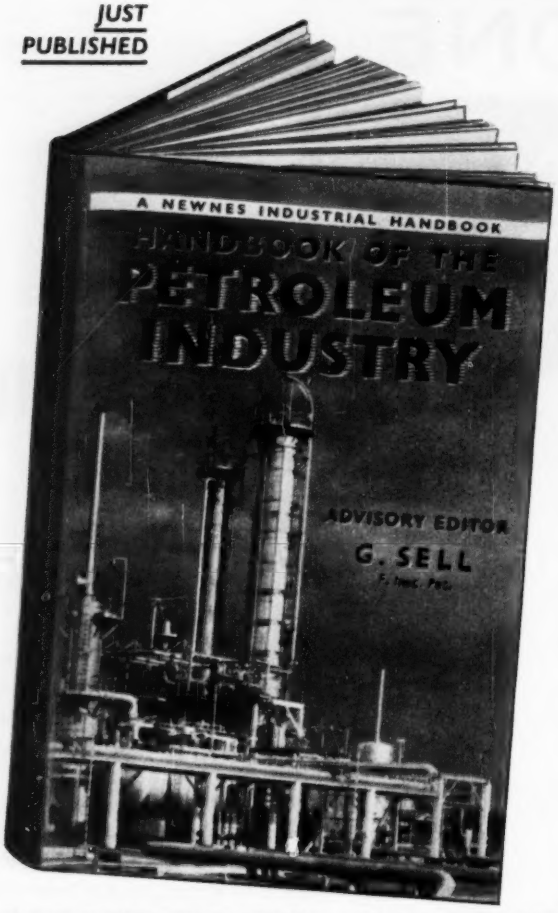

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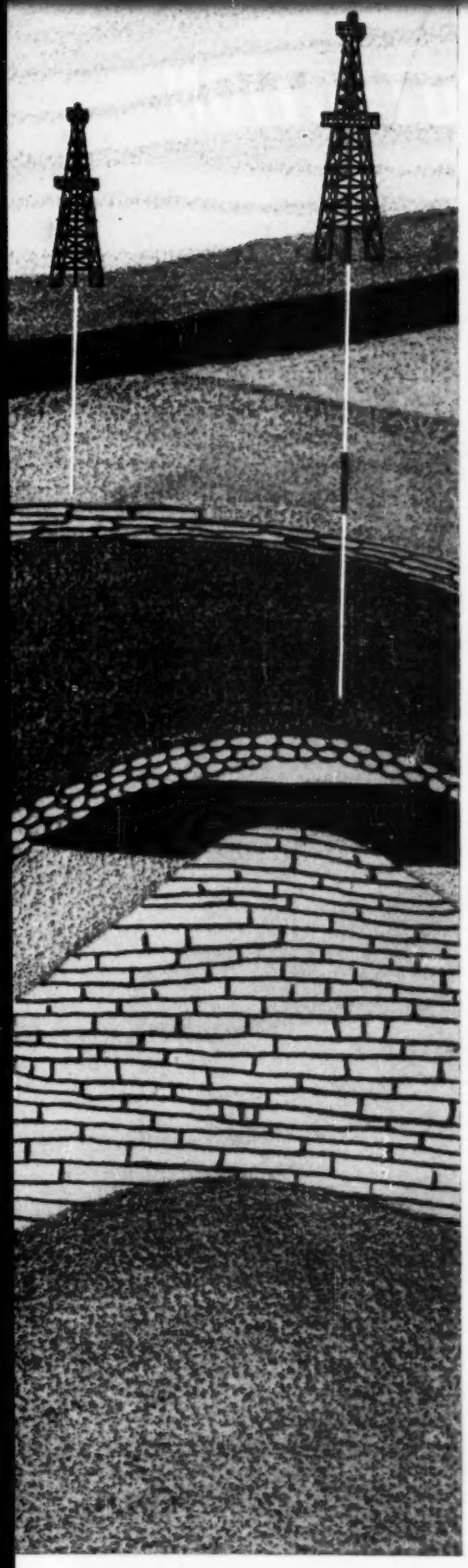

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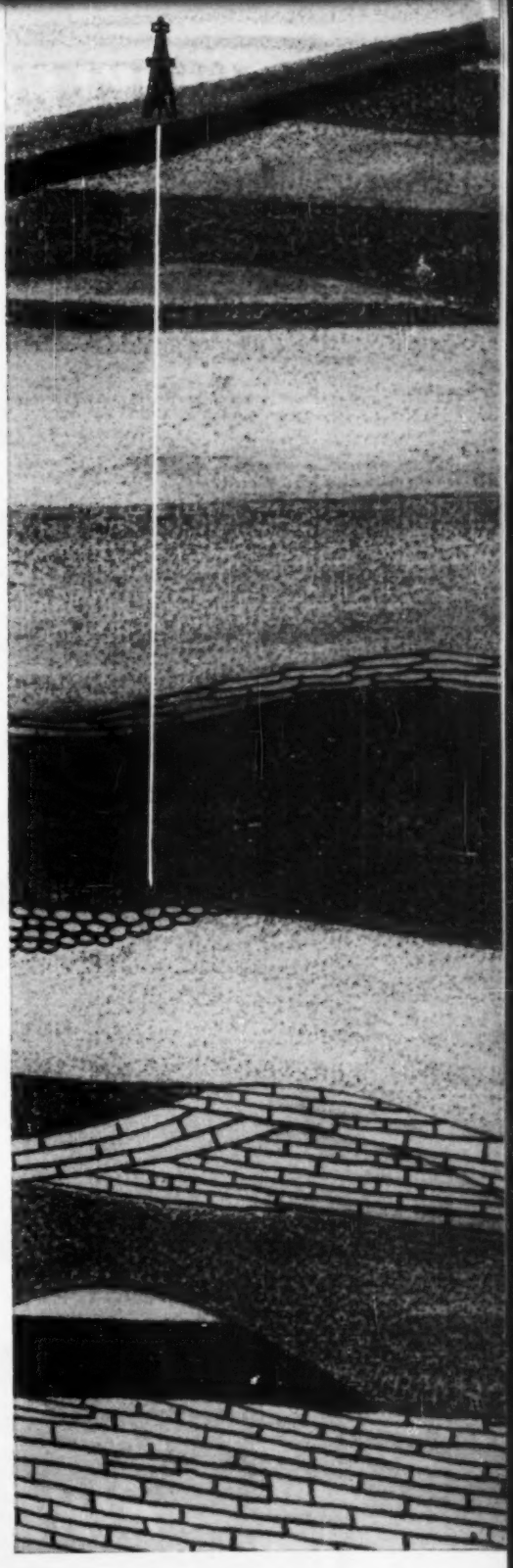

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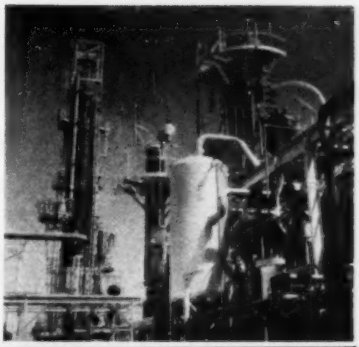
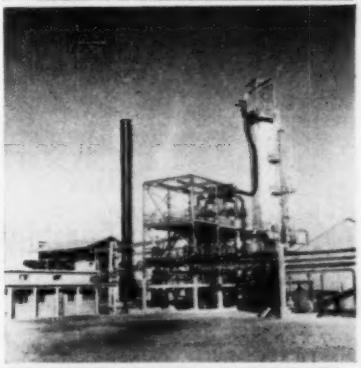


Propane Deasphalting Unit and Vacuum Distillation Unit.

IRAQ

Left
Crude Oil Stabilization Unit at Kirkuk. For the Iraq Petroleum Co.

Right
Crude Oil Distillation Unit at K3 Pump Station.



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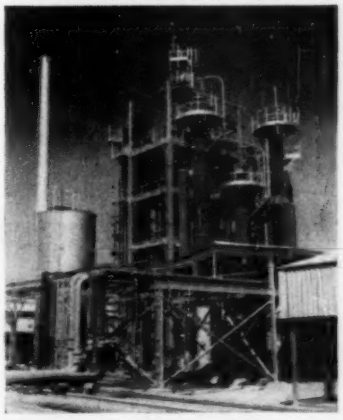

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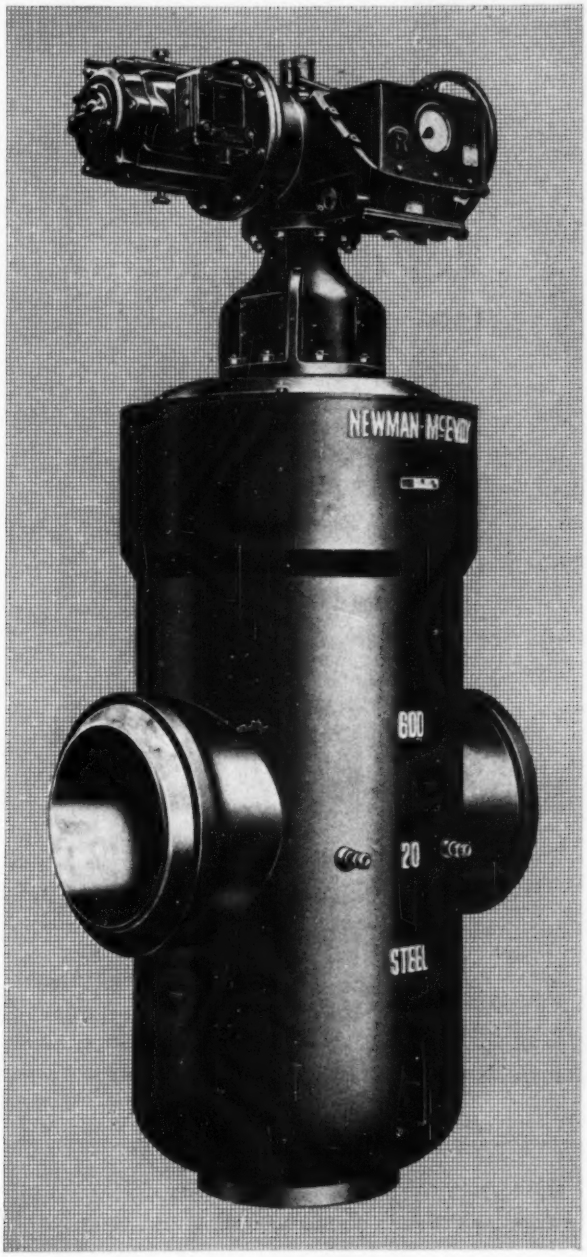

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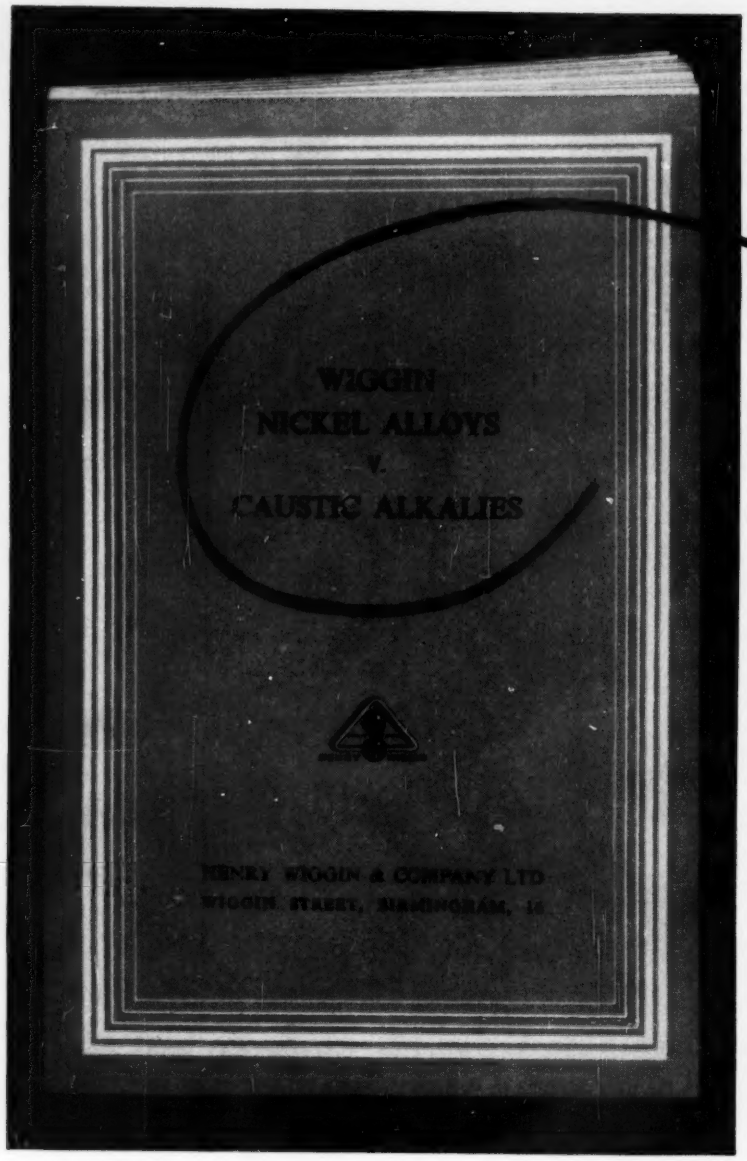

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